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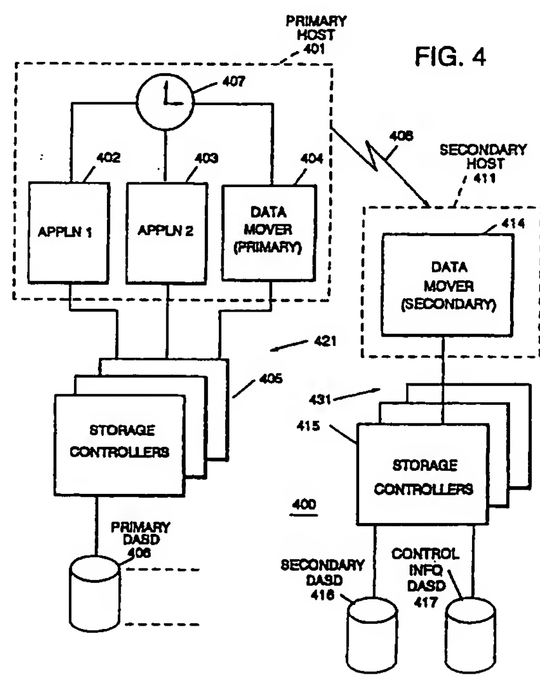
(54) Asynchronous remote data duplexing.

(57) A remote data shadowing system provides storage based, real time disaster recovery capability. Record updates at a primary site cause write I/O operations in a storage subsystem therein. The write I/O operations are time stamped and the time, sequence, and physical locations of the record updates are collected in a primary data mover. The primary data mover groups sets of the record updates and associated control information based upon a predetermined time interval, the primary data mover appending a prefix header to the record updates thereby forming self describing record sets. The self describing record sets are transmitted to a remote secondary site wherein consistency groups are formed such that the record updates are ordered so that the record updates can be shadowed in an order consistent with the order the record updates cause write I/O operations at the primary site.

FIG. 4



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The present invention relates generally to disast r r covery techniques in data processing systems, and mor particularly, to a system f r real-time remote copying of data.

Data processing systems, in conjunction with processing data, typically are required to store large amounts of data (or records), which data can be efficiently accessed, modified, and re-stored. Data storage is typically separated into several different levels, or hierarchically, in order to provide efficient and cost effective data storage. A first, or highest level of data storage involves electronic memory, usually dynamic or static random access memory (DRAM or SRAM). Electronic memories take the form of semiconductor integrated circuits wherein millions of bytes of data can be stored on each circuit, with access to such bytes of data measured in nano-seconds. The electronic memory provides the fastest access to data since access is entirely electronic.

A second level of data storage usually involves direct access storage devices (DASD). DASD storage, for example, can comprise magnetic and/or optical disks, which store bits of data as micrometer sized magnetic or optical altered spots on a disk surface for representing the "ones" and "zeros" that make up those bits of the data. Magnetic DASD, includes one or more disks that are coated with remnant magnetic material. The disks are rotatably mounted within a protected environment. Each disk is divided into many concentric tracks, or closely spaced circles. The data is stored serially, bit by bit, along each track. An access mechanism, known as a head disk assembly (HDA), typically includes one or more read/write heads, and is provided in each DASD for moving across the tracks to transfer the data to and from the surface of the disks as the disks are rotated past the read/write heads. DASDs can store giga-bytes of data with the access to such data typically measured in milli-seconds (orders of magnitudes slower than electronic memory). Access to data stored on DASD is slower due to the need to physically position the disk and HDA to the desired data storage location.

A third or lower level of data storage includes tape and/or tape and DASD libraries. At this storage level, access to data is much slower in a library since a robot is necessary to select and load the needed data storage medium. The advantage is reduced cost for very large data storage capabilities, for example, terabytes of data storage. Tape storage is often used for back-up purposes, that is, data stored at the second level of the hierarchy is reproduced for safe keeping on magnetic tape. Access to data stored on tape and/or in a library is presently of the order of seconds.

Having a back-up data copy is mandatory for many busin sses as data loss could be catastrophic to the business. The time r quir d to recover data lost at th primary storage lev l is also an important recovery consideration. An improv ment in speed over tape or library back-up, includes dual copy. An example of dual copy involves providing additional DASD's so that data is written to the additional DASDs (sometimes r ferred to as mirr ring). Then if the primary DASDs fail, the secondary DASDs can be depended upon for data. A drawback to this approach is that the number of required DASDs is doubled.

Another data back-up alternative that overcomes the need to provide double the storage devices involves writing data to a redundant array of inexpensive devices (RAID) configuration. In this instance, the data is written such that the data is apportioned amongst many DASDs. If a single DASD fails, then the lost data can be recovered by using the remaining data and error correction procedures. Currently there are several different RAID configurations available.

The aforementioned back-up solutions are generally sufficient to recover data in the event that a storage device or medium fails. These back-up methods are useful only for device failures since the secondary data is a mirror of the primary data, that is, the secondary data has the same volume serial numbers (VOLSERs) and DASD addresses as the primary data. System failure recovery, on the other hand, is not available using mirrored secondary data. Hence still further protection is required for recovering data if a disaster occurs destroying the entire system or even the site, for example, earthquakes, fires, explosions, hurricanes, etc. Disaster recovery requires that the secondary copy of data be stored at a location remote from the primary data. A known method of providing disaster protection is to back-up data to tape, on a daily or weekly basis, etc. The tape is then picked up by a vehicle and taken to a secure storage area usually some kilometers away from the primary data location. A problem is presented in this back-up plan in that it could take days to retrieve the back-up data, and meanwhile several hours or even days of data could be lost, or worst, the storage location could be destroyed by the same disaster. A somewhat improved back-up method would be to transmit data to a back-up location each night. This allows the data to be stored at a more remote location. Again, some data may be lost between back-ups since back-up does not occur continuously, as in the dual copy solution. Hence, a substantial data amount could be lost which may be unacceptable to some users.

More recently introduced data disaster recovery solutions include remote dual copy wherein data is backed-up not only remotely, but also continuously. In order to communicate duplexed data from one host processor to another host processor, or from one storage controller to another storage controller, or som combination thereof, a substantial amount of control data is required for r alizing the process. A high ov rhead, how ver, can interfer with a secondary site's ability to k ep up with a primary site's proc ssing, thus threatening the ability of the secondary site to be

able to recover th primary in the event a disaster occurs.

Accordingly it is desired to provide a method and apparatus for providing a real time update f data consistent with the data at a primary processing location using minimal control data, wherein the method and apparatus operates independently of a particular application data being recovered, that is, generic storage media based rather than specific application data based.

An aim of the present invention is to provide an improved system and method for shadowing DASD data to a secondary site for disaster recovery.

According to a first aspect of the present invention, a method for forming consistency groups provides for disaster recovery capability from a remote site. Data updates generated by one or more applications running in a primary processor are received by a primary storage subsystem, wherein the primary storage subsystem causes I/O write operations to write each data update therein. The primary storage subsystem is synchronized by a common timer, and a secondary system, remote from the primary processor, shadows the data updates in sequence consistent order such that the secondary site is available for disaster recovery purposes. Thee method comprising steps of: (a) time stamping each write I/O operation occurring in the primary storage subsystem; (b) capturing write I/O operation record set information from the primary storage subsystem for each data update; (c) generating self describing record sets from the data updates and the respective record set information, such that the self describing record sets are sufficient to re-create a sequence of the write I/O operations; (d) grouping the self describing record sets into interval groups based upon a predetermined interval threshold; and (e) selecting a first consistency group as that interval group of self describing record sets having an earliest operational time stamp, the individual data updates being ordered within the first consistency group based upon time sequences of the I/O write operations in the primary storage subsystem.

In another aspect of the present invention, a primary system has a primary processor running one or more applications, wherein the applications generating record updates, and the primary processor generating self describing record sets therefrom. Each self describing record set is sent to a secondary system remote from the primary system, wherein the secondary system shadows the record updates in sequence consistent order based upon the self describing record sets for real time disaster recovery purposes. The primary processor is coupled to a primary storage subsystem wherein the primary storage subsyst m r ceiv s the rec rd updates and causes I/O write operations for storing each record update therein. The primary processor comprises a sysplex timer for providing a common time source to the applications and to the primary storage subsystem for synchronization purposes, and a primary data mover, synchronized by the sysplex timer, prompts the primary storage subsystem for providing record set information to th primary data mover for each record update. The primary data mover groups a plurality of record updates and each corresponding record set information into time interval groups, and inserts a prefix header thereto. Each time interval group forms the self describing record sets.

A preferred embodiment of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

FIG. 1 is a block diagram of a disaster recovery system having synchronous remote data shadowing capabilities.

FIG. 2 is a flow diagram of a method for providing synchronous remote copy according to the disaster recovery system of FIG. 1.

FIG. 3 is a flow diagram of a method of an I/O error recovery program (I/O ERP) operation.

FIG. 4 is a block diagram of a disaster recovery system having asynchronous remote data shadowing capabilities.

FIG. 5 is a data format diagram showing a prefix header that prefixes read record sets from the primary site of FIG. 4.

FIG. 6 is a data format diagram describing fields making up a read record set.

FIG. 7 is a state table identifying volume configuration information.

FIG. 8 is a master journal as used by the secondary site of FIG. 4.

FIG. 9 is an example sequence for forming a consistency group.

FIG. 10 is a flow diagram showing a method of collecting information and read record sets for forming consistency groups.

FIG. 11 is a flow diagram showing a method of forming consistency groups.

FIG. 12 is a table indicating full consistency group recovery rules application for an ECKD architecture device for a given sequence of I/O operations to a DASD track.

FIG. 13 is a description of the rules to be used in the table of FIG. 12.

FIG. 14 is a flow diagram of a method of writing read record set copies to a secondary site with full consistency group recovery capability.

A typical data processing system may take the form of a host processor, such as an IBM System/360 or IBM System/370 processor for computing and manipulating data, and running, for exampl , data facility storage management subsystem/multiple virtual systems (DFSMS/MVS) software, having at l ast one IBM 3990 storage controller attached th reto, the storage controll r comprising a memory controller

and one or more cach memory typ s inc rporated therein. Th st rage controller is furth r conn cted to a group of direct access storage devices (DASDs) such as IBM 3380 or 3390 DASDs. While the host processor provides substantial computing pow r, the storage controller provides the necessary functions to efficiently transfer, stage/destage, convert and generally access large databases.

Disaster recovery protection for the typical data processing system requires that primary data stored on primary DASDs be backed-up at a secondary or remote location. The distance separating the primary and secondary locations depends upon the level of risk acceptable to the user, and can vary from several kilometers to thousands of kilometers. The secondary or remote location, in addition to providing a backup data copy, must also have enough system information to take over processing for the primary system should the primary system become disabled. This is due in part because a single storage controller does not write data to both primary and secondary DASD strings at the primary and secondary sites. Instead, the primary data is stored on a primary DASD string attached to a primary storage controller while the secondary data is stored on a secondary DASD string attached to a secondary storage controller.

The secondary site must not only be sufficiently remote from the primary site, but must also be able to back-up primary data in real time. The secondary site needs to back-up primary data as the primary data is updated with some minimal delay. Additionally, the secondary site has to back-up the primary data regardless of the application program (e.g., IMS, DB2) running at the primary site and generating the data and/or updates. A difficult task required of the secondary site is that the secondary data must be order consistent, that is, secondary data is copied in the same sequential order as the primary data (sequential consistency) which requires substantial systems considerations. Sequential consistency is complicated by the existence of multiple storage controllers each controlling multiple DASDs in a data processing system. Without sequential consistency, secondary data inconsistent with primary data would result, thus corrupting disaster recovery.

Remote data duplexing falls into two general categories, synchronous and asynchronous. Synchronous remote copy involves sending primary data to the secondary location and confirming the reception of such data before ending a primary DASD input/output (I/O) operation (providing a channel end (CE) and device end (DE) to the primary host). Synchronous copy, therefore, slows the primary DASD I/O response time while waiting for secondary confirmation. Primary I/O r sponse delay is increas d proportionately with th distance b tw en the primary and secondary systems - a factor that limits th remote distance to tens of kilomet rs. Synchronous copy, h w v r, provides sequentially consistent data at th s condary sit with relatively littl system ov rhead.

Asynchronous remote copy provides better primary application system performance because the primary DASD I/O operation is compl ted (providing a channel end (CE) and device end (DE) to the primary host) before data is confirmed at the secondary site. Therefore, the primary DASD I/O response time is not dependent upon the distance to the secondary site and the secondary site could be thousands of kilometers remote from the primary site. A greater amount of system overhead is required, however, for ensuring data sequence consistency since data received at the secondary site will often not be in order of the primary updates. A failure at the primary site could result in some data being lost that was in transit between the primary and secondary locations.

Synchronous real time remote copy for disaster recovery requires that copied DASD volumes form a set. Forming such a set further requires that a sufficient amount of system information be provided to the secondary site for identifying those volumes (VOLSERs) comprising each set and the primary site equivalents. Importantly, the secondary site forms a "duplex pair" with the primary site and the secondary site must recognize when one or more volumes are out of sync with the set, that is, "failed duplex" has occurred. Connect failures are more visible in synchronous remote copy than in asynchronous remote copy because the primary DASD I/O is delayed while alternate paths are retried. The primary site can abort or suspend copy to allow the primary site to continue while updates for the secondary site are queued, the primary site marking such updates to show the secondary site is out of sync. Recognizing exception conditions that may cause the secondary site to fall out of sync with the primary site is needed in order that the secondary site be available at any time for disaster recovery. Error conditions and recovery actions must not make the secondary site inconsistent with the primary site.

Maintaining a connection between the secondary site and the primary site with secondary DASD present and accessible, however, does not ensure content synchronism. The secondary site may lose synchronism with the primary site for a number of reasons. The secondary site is initially out of sync when the duplex pair is being formed and reaches sync when an initial data copy is completed. The primary site may break the duplex pair if the primary site is unable to write updated data to the secondary site in which case the primary site writes updates to the primary DASD under suspended dupl x pair conditions so that th updating application can continue. The primary site is thus running exposed, that is, without current disaster protection copy until the duplex pair is restored. Upon restoring the duplex pair, the secondary site is not imm diat ly in sync. After applying now pending up-

dates, the secondary site returns to sync. Th primary site can also cause the s condary site to lose sync by issuing a suspend command for that volum to the primary DASD. The secondary site re-syncs with the primary site after the suspend command is ended, duplex pair is re-established, and pending updates are copied. On-line maintenance can also cause synchronization to be lost.

When a secondary volume is out of sync with a primary volume, the secondary volume is not useable for secondary system recovery and resumption of primary applications. An out-of-sync volume at the secondary site must be identified as such and secondary site recovery-takeover procedures need to identify the out-of-sync volumes for denying application access (forcing the volumes off-line or changing their VOLSERs). The secondary site may be called upon to recover the primary site at any instant wherein the primary site host is inaccessible - thus the secondary site requires all pertinent information about a sync state of all volumes. The secondary storage subsystem, that is the secondary storage controllers and DASD, is unable to determine all conditions causing the primary site to break synchronism due to primary site-encountered exceptions. For example, the primary site may break a duplex pair if the primary site is unable to access the secondary peer due to a primary I/O path or link failure that the secondary site is unaware of. In this case the secondary site shows in-sync state while the primary site indicates the duplex pair is broken.

External communication may notify the secondary site that an out-of-sync duplex pair volume exists. This is realizable by employing a user systems management function. Primary I/O operations end with channel end/device end/unit check (CE/DE/UC) status and sense data indicates the nature of the error. With this form of I/O configuration an error recovery program (ERP) processes the error and send an appropriate message to the secondary processor before posting the primary application that I/O is complete. The user is then responsible to recognize the ERP suspend duplex pair message and secure that information at the secondary location. When the secondary site is depended upon to become operational in place of the primary site, a start-up procedure brings the secondary DASD on-line to the secondary host wherein sync status stored in the secondary DASD subsystem is retrieved for ensuring that out-of-sync volumes are not brought on-line for application allocation. This sync status merged with all ERP suspend duplex pair messages gives a complete picture of the secondary out-of-sync volumes.

Referring now to FIG. 1, a disaster recov ry syst m 10 is shown having a primary site 14 and a s condary site 15, wherein the s condary site 15 is located, for example, 20 kilo-meters remote from th primary sit 14. The primary site 14 includes a host processor or primary processor 1 having an application and system I/O and Error Recov ry Program 2 running therein (hereinafter referred to as I/O ERP 2). The primary processor 1 could be, for example, an IBM Ent rprise Systems/9000 (ES/9000) processor running DFSMS/MVS operating software and further may have several application programs running thereon. A primary storage controller 3, for example, an IBM 3990 Model 6 storage controller, is connected to the primary processor 1 via a channel 12. As is known in the art, several such primary storage controllers 3 can be connected to the primary processor 1, or alternately, several primary processors 1 can be attached to the primary storage controllers 3. A primary DASD 4, for example, an IBM 3390 DASD, is connected to the primary storage controller 3. Several primary DASDs 4 can be connected to the primary storage controller 3. The primary storage controller 3 and attached primary DASD 4 form a primary substorage system. Further, the primary storage controller 3 and the primary DASD 4 could be single integral units.

The secondary site 15 includes a secondary processor 5, for example, an IBM ES/9000, connected to a secondary storage controller 6, for example an IBM 3990 Model 3, via a channel 13. A DASD 7 is further connected to the secondary storage controller 6. The primary processor 1 is connected to the secondary processor 5 by at least one host-to-host communication link 11, for example, channel links or telephone T1/T3 line links, etc. The primary processor 1 may also have direct connectivity with the secondary storage controller 6 by, for example, multiple Enterprise Systems Connection (ESCON) links 9. As a result, the I/O ERP 2 can communicate, if required, with the secondary storage controller 6. The primary storage controller 3 communicates with the secondary storage controller 6 via multiple peer-to-peer links 8, for example, multiple ESCON links.

When a write I/O operation is executed by an application program running in the primary processor 1, a hardware status channel end/device end (CE/DE) is provided indicating the I/O operation completed successfully. Primary processor 1 operating system software marks the application write I/O successful upon successful completion of the I/O operation, thus permitting the application program to continue to a next write I/O operation which may be dependent upon the first or previous write I/O operation having successfully completed. On the other hand, if the write I/O operation was unsuccessful, the I/O status of channel end/device end/unit check (hereinafter referred to as CE/DE/UC) is presented to the primary processor 1 operating system software. Having present d unit check, the I/O ERP 2 takes control obtaining specific sense information fr m the primary storag controller 3 r garding the nature of th fail d write I/O operation. If a unique error to a volume oc-

curs then a unique status related t that rror is provided to th I/O ERP 2. The I/O ERP 2 can th r after perform n w peer-to-peer synchronization rror recovery for maintaining data integrity b twe n the primary storage controller 3 and the secondary storage controller 6, or in the worst case, betw n the primary processor 1 and the secondary processor 5.

Referring to FIGs 2 and 3, the error recovery procedure is set forth. In FIG. 2, a step 201 includes an application program running in the primary processor 1 sending a data update to the primary storage controller 3. At step 203 the data update is written to the primary DASD 4, and the data update is shadowed to the secondary storage controller 6. At step 205 the duplex pair status is checked to determine whether the primary and secondary sites are synchronized. If the duplex pair status is in a synchronized state, then the data update is written to the secondary DASD 7 at step 207 while processing then continues at the primary processor 1 via application programs running thereat.

In the case that the duplex pair is in a "failed" state, then at step 209 the primary storage controller 3 notifies the primary processor 1 that duplex pair has suspended or failed. The duplex pair can become "failed" due to communication failure between the primary storage controller 3 and the secondary storage controller 6 via communication links 8. Alternatively, duplex pair can become "failed" due to errors in either the primary or secondary subsystem. If the failure is in the communication links 8, then the primary storage controller 3 is unable to communicate the failure directly to the secondary storage controller 6. At step 211 the primary storage controller 3 returns I/O status CE/DE/UC to the primary processor 1. The I/O ERP 2 quiesces the application programs hence taking control of the primary processor 1 at step 213 for error recovery and data integrity before returning control to the application requesting the write I/O operation.

FIG. 3 represents steps performed by the I/O ERP 2. The I/O ERP 2 issues a sense I/O to the primary storage controller 3 at step 221. The sense I/O operation returns information describing the cause of the I/O error, that is, the data description information is unique to the storage controllers or duplex pair operation regarding specific errors. In the event that the data description information indicates that the peer-to-peer communication links 8 have failed between the primary storage controller 1 and the secondary storage controller 6, then at step 223 the I/O ERP 2 issues a storage controller level I/O operation against the primary storage controller 3 and the secondary storage controller 6 indicating that the affected volum is to be plac d in failed synchronous remote c py state. This secondary storage controll r 6 is able to r ceive th state of the affected volume from the I/O ERP 2 via the - multiple ESCON links 9 or the host-to-host communication link 11. Consequently, the current status of the duplex pair op ration is maintained at b th the primary processor 1 and the secondary processor 5 in conjunction with applications running in the primary processor 1. Consoles 18 and 19 ar provided for communicating information from the primary processor 1 and secondary processor 4, respectively, wherein the I/O ERP posts status information to both consoles 18 and 19.

Data integrity has been maintained at step 225 upon successful completion of the failed synchronous remote copy I/O operation to the primary storage controller 3 and the secondary storage controller 6. Therefore, if a recovery is attempted at the secondary site 15 the secondary storage controller 6 identifies the volume marked "failed synchronous remote copy" as not being useable until data on that volume are synchronized with other data in that synchronization group by data recovery means (conventional data base logs and/or journals for determining the state of that data on the volume).

Step 227 tests to determine whether the I/O ERP 2 received successful completion of the I/O operations at the primary storage controller 3 and the secondary storage controller 6 on the failed synchronous remote copy status update. Upon successful completion, the I/O ERP 2 returns control to the Primary processor 1 at step 229. Otherwise step 231 performs a next level recovery notification which involves notifying an operator, via the console 18, of the failed volume and that a status of that volume at either the primary storage controller 3 or the secondary storage controller 6 may not be correct. The notification is shadowed to the secondary site 15, via the console 19 or a shared DASD data set, for indicating the specific volume status there.

An error log recording data set is updated at step 233. This update is written to either the primary DASD 4 or some other storage location and is shadowed to the secondary site 15. Having completed the error recovery actions, the I/O ERP 2, at step 235, posts to the primary application write I/O operation a "permanent error" for causing the primary application an error normal "permanent error" recovery for the failed write I/O operation. Once the error is corrected, the volume states can be recovered, first to pending (recopy changed data) and then back to full duplex. The data may later be re-applied to the secondary DASD 7 once duplex pair is re-established.

When establishing a duplex pair a volume can be identified as CRITICAL according to a customer's needs. For a CRITICAL volume, when an operation results in failing a duplex pair, a permanent error failure of the primary volume is reported irrespective of the actual rror's location. With CRIT=Y, all subsequent attempts to write to the primary DASD 405 of the failed pair will receive a permanent error, ensuring that no data is writt n to that primary volume that can-

not also be shadowed to the paired secondary volume. This permits complete synchronization with the primary application actions and the I/O data operations when required.

Consequently, th disaster recovery system 10 described herein, introduces outboard synchronous remote copy such that a primary host process error recovery procedure having an I/O order (channel command word (CCW)) may change a status of a primary and secondary synchronous remote copy volume from duplex pair to failed duplex thereby maintaining data integrity for several types of primary and secondary subsystem errors. Storage based back-up, rather than application based back-up, wherein data updates are duplicated in real time has been provided. The disaster recovery system 10 also attempts several levels of primary/secondary status updates, including: (1) primary and secondary storage controller volume status updates; (2) primary and secondary host processor notification on specific volume update status via operator messages or error log recording common data sets; and (3) CRITICAL volume indication, future updates to the primary volume can be prevented if the volume pair goes failed duplex. Hence, real time, full error disaster recovery is accomplished.

Asynchronous remote data shadowing is used when it is necessary to further increase a distance between primary and secondary sites for reducing the probability that a single disaster will corrupt both primary and secondary sites, or when primary application performance impact needs to be minimized. While the distance between primary and secondary sites can now stretch across the earth or beyond, the synchronization of write updates across multiple DASD volumes behind multiple primary subsystems to multiple secondary subsystems is substantially more complicated. Record write updates can be shipped from a primary storage controller via a primary data mover to a secondary data mover for shadowing on a secondary storage subsystem, but the amount of control data passed therebetween must be minimized while still being able to re-construct an exact order of the record write updates on the secondary system across several storage controllers as occurred on the primary system across multiple DASD volumes behind several storage controllers.

FIG. 4 depicts an asynchronous disaster recovery system 400 including a primary site 421 and a remote or secondary site 431. The primary site 421 includes a primary processor 401, for example, an IBM ES/9000 running DFSMS/MVS host software. The primary processor 401 further includes application programs 402 and 403, for example, IMS and DB2 applications, and a primary data mover (PDM) 404. A common sysplex clock 407 is included in the primary processor 401 for providing a common reference to all applications (402, 403) running ther in, wh rein all system clocks or time sources (not shown) synchronize to the sysplex clock 407 nsuring all time d pendent processes are properly timed relative to one another. The primary storage controllers 406, for example, synchronize to a resolution appropriate to ensure differentiation between record write update times, such that no two consecutive write I/O operations to a single primary storage controller 404 can exhibit the same time stamp value. The resolution, and not the accuracy, of the sysplex timer 407 is critical. The PDM 404, though shown connected to the sysplex timer 407, is not required to synchronize to the sysplex timer 407 since write I/O operations are not generated therein. A sysplex timer 407 is not required if the primary processor 401 has a single time reference (for example, a single multi-processor ES/9000 system).

A plurality of primary storage controllers 405, for example, IBM 3990 Model 6 storage controllers, are connected to the primary processor 401 via a plurality of channels, for example, fiber optic channels. Connected to each primary storage controller 405 is at least one string of primary DASDs 406, for example, IBM 3390 DASDs. The primary storage controllers 405 and the primary DASDs 406 form a primary storage subsystem. Each storage controller 405 and primary DASD 406 need not be separate units, but may be combined into a single drawer.

The secondary site 431, located for example, some thousands of kilometers remote from the primary site 421, similar to the primary site 421, includes a secondary processor 411 having a secondary data mover (SDM) 414 operating therein. Alternatively, the primary and secondary sites can be the same location, and further, the primary and secondary data movers can reside on a single host processor (secondary DASDs may be just over a fire-wall). A plurality of secondary storage controllers 415 are connected to the secondary processor 411 via channels, for example, fiber optic channels, as is known in the art. Connected to the storage controllers 415 are a plurality of secondary DASDs 416 and a control information DASD(s) 417. The storage controllers 415 and DASDs 416 and 417 comprise a secondary storage subsystem.

The primary site 421 communicates with the secondary site 431 via a communication link 408. More specifically, the primary processor 401 transfers data and control information to the secondary processor 411 by a communications protocol, for example, a virtual telecommunications access method (VTAM) communication link 408. The communication link 408 can be realized by several suitable communication methods, including telephone (T1, T3 lin s), radio, radio/telephone, microwave, satellit , etc.

Th asynchron us data shadowing system 400 encompasses collecting control data from the primary storage controllers 405 so that an ord r of all

data writes to the primary DASDs 406 is pres rved and applied to the s condary DASDs 416 (preserving the data write ord r across all primary storage subsystems). The data and control information transmit- t d t the secondary site 431, must be sufficient such that the presence of the primary site 421 is no longer required to preserve data integrity.

The applications 402, 403 generate data or record updates, which record updates are collected by the primary storage controllers 405 and read by the PDM 404. The primary storage controllers 405 each grouped its respective record updates for an asynchronous remote data shadowing session and provides those record updates to the PDM 404 via non-specific primary DASD 406 READ requests. Transferring record updates from the primary storage controllers 405 to the PDM 404 is controlled and optimized by the PDM 404 for minimizing a number of START I/O operations and time delay between each read, yet maximizing an amount of data transferred between each primary storage controller 405 and the primary processor 401. The PDM 404 can vary a time interval between non-specific READs to control this primary storage controller-host optimization as well as a currency of the record updates for the secondary DASDs 416.

Collecting record updates by the PDM 404, and transmitting those record updates to the SDM 414, while maintaining data integrity, requires the record updates to be transmitted for specific time intervals and in appropriate multiple time intervals with enough control data to reconstruct the primary DASDs 406 record WRITE sequence across all primary storage subsystems to the secondary DASDs 416. Re-constructing the primary DASDs 406 record WRITE sequences is accomplished by passing self describing records from the PDM 404 to the SDM 414. The SDM 414 inspects the self describing records for determining whether any records for a given time interval have been lost or are incomplete.

FIGs 5 and 6 show a journal record format created by the PDM 404 for each self describing record, including a prefix header 500 (FIG. 5), and a record set information 600 (FIG. 6) as generated by the primary storage controller 405. Each self describing record is further journaled by the SDM 414 for each time interval so that each self describing record can be applied in time sequence for each time interval to the secondary DASDs 416.

Referring now to FIG. 5, the prefix header 500, which is inserted at the front of each record set, includes a total data length 501 for describing the total l ngth of the prefix header 500 and actual primary record set information 600 that is transmitted to the SDM 414 for each record set. An operational time stamp 502 is a time stamp indicating a start time for the operational set that the PDM 404 is currently pr c- essing. The operational time stamp 502 is generated by the PDM 404 (according to the sysplex timer 407) when performing a READ RECORD SET function to a set of the primary storage controllers 405. An I/O time 610 (FIG. 6) of th primary DASDs 406 write is unique for each primary storage controller 405 READ RECORD SET. The operational time stamp 502 is common across all storage controllers.

A READ RECORD SET command is issued by the PDM 404 and can be predicated upon one of the following conditions:

(1) Primary storage controller 405 attention interrupt based upon that primary storage controller predetermined threshold;

(2) Primary processor 401 timer interrupt based upon a predetermined time interval; or

(3) Record set information indicates additional information on outstanding record sets available but not yet read.

Condition (2) uses a timer interval to control how far behind the secondary system 431 executes during periods of low activity. Condition (3) occurs when the PDM 404 fails to drain all record sets during a processing interval which drives further activity for ensuring that the PDM 404 keeps up with primary storage controller 405 activity.

A time interval group number 503 is supplied by the PDM 404 to identify a time interval (bounded by operational time stamp 502 and a records read time 507) for which the current record sets belong (sets of records across all primary storage controllers 405 for a given time interval group form consistency groups). A sequence number within group 504 is derived based upon a hardware provided identification (to the PDM 404) of a write sequence order of application WRITE I/Os for primary storage controller 405 for each record set within a given time interval group 503. A primary SSID (substorage identification) 505 uniquely identifies the specific primary storage controller of the primary storage controllers 405 for each record set. A secondary target volume 506 is assigned by either the PDM 404 or the SDM 414 depending upon performance considerations. A records read time 507 supplies an operational time stamp that is common to all primary storage controllers 405 indicating an end time for the PDM 404 read record set process current interval.

The operational time stamp 502 and the records read time 507 are used by the PDM 404 to group sets of read record sets from each of the primary storage controllers 405. Time synchronization for grouping sets of read record sets is key only to the PDM 404 and as such, the PDM 404 could be synchronized to a central processing unit (CPU) clock running only the PDM 404 not attached to the syspelx timer 407. Th PDM 404 does not write record updates, but the record updat s, as stated previously, must be synchronized to a common time sourc .

Referring now to FIG. 6, th record set informa-

tion 600 is gen rated by th primary st rage controllers 405 and collected by the PDM 404. Update Specific Information 601-610, includes a primary device unit address 601 of each record indicating the actual primary DASD 406 that the record updat occurred on. A cylinder number/head number (CCHH) 602 indicates a location on primary DASD 406 for each record update. Primary SSID 603, the primary storage controller session identifier is the same as primary SSID 505. Status flags 604 provide status information regarding whether specific data records 620 follow. Sequence numbers 605 and 630 assign a number to each record for indicating whether the entire record set has been read (all data transferred to the PDM 404). Primary DASD write I/O type 606 is an operation indicator identifying the type of write operation performed on each record, the operation indicators including: update write; format write; partial track records follow; full track data follows; erase command performed; or write any performed. Search argument 607 indicates initial positioning information for the first read record set data record 620. A sector number 608 identifies that sector that the record was updated at. Count field 609 describes a number of specific record data fields 620 that follow. A host application time when the primary DASD 406 write update occurred is recorded in time of updates 610. Specific record data 620 provides a count/key/data (CKD) field of each record update. Lastly, the sequence number 630 is compared to the sequence number 605 for indicating whether the entire read record set was transferred to the PDM 404.

The update records are handled in software groups called consistency groups so that the SDM 414 can copy the record updates in the same order they were written at the primary DASDs 406. The information used for creating the consistency groups (across all record sets collected from all storage controllers 405) includes the: operational time stamp 502; time interval group number 503; sequence number within group 504; primary controller SSID 505; records read time 507; primary device address 601; the primary SSID 603; and the status flags 604. The information used for determining whether all records for a time interval group have been received for each storage controller 405 at the SDM 414 includes the: time interval group number 503; sequence number within group 504; physical controller ID 505; the primary SSID 603; and a total number of read record sets returned from each primary storage controller 405 for each operational time interval. The information necessary to place record updates on the secondary DASDs 416 equivalently to the primary DASDs 406 record updates with full r cov r possible includes the: secondary target volume 506; CCHH 602; primary DASD write I/O type 606; search argum nt 607; sector number 608; count 609; time of updat s 610; and the specific record data 620.

FIGs 7 and 8 show a state table 700 and a master journal 800, resp ctively, for describing a current journal contents, which simplifies recov ry time and journal transfer time. The state table 700 provid s configuration information, collected by and common to the PDM 404 and SDM 414, and includes primary storage controller session identifiers (SSID numbers) and the volumes therein, and the corresponding secondary storage controller session identifiers and the corresponding volumes. Thus the configuration information tracks which primary volumes 710 or primary DASD extents map to secondary volumes 711 or secondary DASD extents. With a simple extension to the state table 700 indicating partial volume extents 712 (CCHH to CCHH), partial volume remote copy can be accomplished using the same asynchronous remote copy methods described herein, but for a finer granularity (track or extent) than full volume.

The master journal 800 includes: consistency group number; location on journal volumes; and operational time stamp. The master journal 800 further maintains specific record updates as grouped in consistency groups. The state table 700 and master journal 800 support disaster recovery, and hence must be able to operate in a stand-alone environment wherein the primary system 401 no longer exists.

A time stamp control is placed at the front and back of each master journal 800 to ensure that the entire control entry was successfully written. The time stamp control is further written to the secondary DASDs 417. The control elements include dual entries (1) and (2), wherein one entry is always a current entry, for example:

(1) Timestamp control | Control Info | Timestamp Control

(2) Timestamp Control | Control Info | Timestamp Control.

At any point in time either entry (1) or (2) is the current or valid entry, wherein a valid entry is that entry with equal timestamp controls at the front and back. Disaster recovery uses the valid entry with the latest timestamp to obtain control information. This control information, along with state information (environmental information regarding storage controllers, devices, and applied consistency groups), is used for determining what record updates have been applied to the secondary storage controllers 415.

After all read record sets across all primary storage controllers 405 for a predetermined time interval are received at the secondary site 431, the SDM 414 interprets the received control information and applies the received read record sets to the secondary DASDs 416 in groups of record updates such that the record updates are applied in the sam sequence that those record updates were originally written on the primary DASDs 406. Thus, all primary application order (data int grity) consist ncy is maintain d at the secondary site 431. This process is hereinafter ref r-

red to as forming consistency groups. Forming consistency groups is based on the following assumptions: (A) application writes that are independent can be performed in any ord r if they do not violate controller sequence order; (B) application writes that are dependent must be performed in timestamp order, hence an application cannot perform a dependent write number two before receiving control unit end, device end from write number one; and (C) a second write will always be either (1) in a same record set consistency group as a first write with a later timestamp or (2) in a subsequent record set consistency group.

Referring to FIG. 9, an example of forming a consistency group (the consistency group could be formed at either the primary site 421 or secondary site 431), for example, for storage controllers SSID 1, SSID 2, and SSID 3 is shown (any number of storage controllers can be included but three are used in this example for clarity). Time intervals T1, T2 and T3 are assumed to occur in ascending order. An operational time stamp 502 of time interval T1 is established for storage controllers SSID 1, SSID 2 and SSID 3. The PDM 404 obtains record set data from storage controller SSIDs 1, 2, and 3 for time interval T1-T3. The record sets for SSIDs 1, 2, and 3 for time interval T1 are assigned to time interval group 1, G1 (time interval group number 503). The sequence number within group 504 is shown for each SSID 1, 2, and 3, wherein SSID has three updates as 11:59. 12:00, and 12:01, SSID 2 has two updates at 12:00 and 12:02, and SSID 3 has three updates at 11:58, 11:59, and 12:02. Record sets of time intervals T2 and T3 are listed but example times of updates are not given for simplicity.

Consistency group N can now be formed based upon the control information and record updates received at the secondary site 431. In order to ensure that no record update in time interval group number one is later than any record update of time interval group number two, a min-time is established which is equal to a the earliest read record set time of the last record updates for each storage controller SSID 1, 2, and 3. In this example then, min-time is equal to 12:01. Any record updates having a read record set time greater than or equal to min-time is included in the consistency group N + 1. If two record update times to a same volume were equal, though unlikely given sufficient resolution of the sysplex timer 407, the record update having the earlier sequence number within the time interval group N is kept with that group for consistency group N. The record updates are now ordered based upon read record set times. R cord updates having equal times will cause the record update having th lower sequ nce number to be place before the later sequence numbered record updat . Alt rnatively, r cord updates having qual time stamps, but to differing volumes, may be ordered arbitrarily as long as they are kept in the same consistency group.

If a primary storage controller 405 fails to complete a response to a read record set during a specified time interval, then a consistency group cannot be formed until that primary storage controller 405 completes. In the event that the primary storage controller 405 fails to complete its operation, then a missing interrupt results causing a system missing interrupt handler to receive control and the operation will be terminated. On the other hand, if the primary storage controller 405 timely completes the operation then the I/O will be driven to completion and normal operation will continue. Consistency group formation expects that write operations against the primary storage controllers 405 will have time stamps. Some programs, however, will cause writes to be generated without time stamps, in which case the primary storage controller 405 will return zeros for the time stamp. Consistency group formation can bound those records without time stamps based upon the timestamp that the data was read. If too many record updates without time stamps occur over a time interval such that the record updates are not easily bounded by consistency group times, then an error that the duplex volumes are out of synchronization may result.

FIGs 10 and 11 are flow diagrams presenting the method of forming consistency groups. Referring to FIG. 10, the process starts at step 1000 with the primary site 421 establishing remote data shadowing to occur. At step 1010 all application I/O operations are time stamped using the sysplex timer 407 as a synchronization clock (FIG. 4). The PDM 404 starts a remote data shadowing session with each primary storage controller 405 at step 1020 which includes identifying those primary volumes that will have data or records shadowed. Record set information 600 is trapped by the primary storage controllers 405 for each application WRITE I/O operation (see FIG. 6) by step 1030.

Step 1040 involves the PDM 404 reading the captured record set information 600 from each primary storage controller 405 according to a prompt including an attention message, a predetermined timing interval, or a notification of more records to read as described earlier. When the PDM 404 begins reading record sets, at step 1050, the PDM 404 prefixes each record set with a prefix header 500 (see FIG. 5) for creating specific journal records (a journal record includes the prefix header 500 and the record set information 600). The journal records contain the control information (and records) necessary for forming consistency groups at the secondary site 431 (or at the primary site 421).

At step 1060 the PDM 404 transmits the gen r-ated journal records t the SDM 414 via the communications link 408 (or within the same data mov r system if the consist ncy groups are form d therein). The SDM 414 us s th state tabl 700 at step 1070

to gather the received record updates by group and sequence numbers for ach time interval group and primary storage controller 405 established for the data shadowing session. The SDM 414 inspects the journal records at step 1080 to determine whether all record information has been received for each time interval group. If the journal records are incomplete, then step 1085 causes the SDM 414 to notify the PDM 404 to resend the required record sets. If the PDM 404 is unable to correctly resend, then the duplex volume pair is failed. If the journal records are complete, then step 1090 is performed which encompasses the SDM 414 forming the consistency groups.

Referring to FIG. 11, steps 1100-1160 representing step 1090 (FIG. 10) for forming consistency groups is shown. Consistency group formation starts at step 1100 wherein each software consistency group is written to an SDM 414 journal log ("hardened") on the secondary DASD 417 (FIG. 4). Step 1110 performs a test for determining whether the time interval groups are complete, that is, each primary storage controller 405 must have either presented at least one read record set buffer or have confirmation from the PDM 404 that no such record updates were placed in the record set buffer, and all read record set buffers with data (or null) must have been received by the SDM 414. If a time interval group is incomplete, then step 1110 retries reading the record sets from the primary storage controller 405 until the required data is received. If errors occur, a specific duplex volume pair or pairs may be failed. Having received complete time interval groups, step 1120 determines a first consistency group journal record. The first (or current) consistency group journal record is that record which contains the earliest operational time stamp 502 and the earliest time of update 610 of all records having equal operational time stamps 502.

Step 1130 inspects the records contained in the current consistency group journal record to determine which record will be the last record to be included therein (some records will be dropped and included in the next consistency group journal record). The last record in the current consistency group journal record is determined as a minimum update time (min-time) of the maximum update times for each primary storage controller 405 (that is, the last update of each primary storage controller 405 is compared and only the earliest of these remains in the current consistency group journal record).

Those remaining record updates in the current consistency group journal record are ordered according to time of update 610 and sequence number within group 504 by step 1140. A primary storage controller 405 that had no record updates does not participate in the consistency group. At step 1150, the remaining record updates of the curr nt consistency gr up (having update times lat r than min-time) are pass d to the next consistency group. Each s qu nce number within a group 504 should nd with a null buffer indicating that all read record sets have been read for that operational time interval. If the null buffer is absent, then the step 1120 of defining the last record in th current software consistency group, coupled with the records read time 507 and time of update 610 can be used to determine the proper order of the application WRITE I/O operations across the primary storage controllers 405.

Step 1160 represents a back-end of the remote data shadowing process wherein specific write updates are applied to secondary DASDs 416 under full disaster recovery constraint. If when writing the updates to the secondary DASDs 416 an I/O error occurs, or the entire secondary site 431 goes down and is re-initialized, then the entire consistency group that was in the process of being written can be re-applied from the start. This permits the remote shadowing to occur without having to track which secondary DASDs 416 I/Os have occurred, which I/Os have not occurred, and which I/Os were in process, etc.

A key component of step 1160 is that the PDM 414 causes the records to be written efficiently to the secondary DASDs 416 so that the secondary site 431 can keep pace with the primary site 421. The requisite efficiency is accomplished, in part, by concurrently executing multiple I/O operations to different secondary DASDs 416. Serially writing one secondary DASD 416 at a time would cause the secondary site 431 to fall too far behind the primary site 421. Yet more efficiency is gained at the secondary site 431 by writing the records for each consistency group destined for a single secondary device via a single channel command word (CCW) chain. Within each single CCW chain, the I/O operations therein can be further optimized as long as those I/O operations to each secondary DASD 416 data track are maintained in the order of occurrence on the primary volumes.

Optimizing secondary I/O operations for specific consistency groups and within single CCW chains is based in part upon the pattern of primary write I/O operations, and in part upon the physical characteristics of the secondary DASDs 416. Optimization may vary somewhat depending upon whether secondary DASD 415 is count/key/data (CKD), extended count/key/data (ECKD), fixed block architecture (FBA), etc. Consequently, a number of WRITE I/Os (m) to a primary DASD 406 volume during a given time interval can be reduced to a single START I/O operation to a secondary DASD 416 volume. This optimization of the number of START I/Os to the secondary storage controllers 415 of m:1 can allow the secondary DASDs 416 to catch up with and thereby clos r shadow the record updates at the primary sit 421.

A key to successful remote data shadowing, and hence s condary I/O ptimization, is minimizing un r c verabl errors in any of th concurrent multiple I/O operations to secondary DASDs 416 so that con-

sistent copies are available for recovery. A failure in a given secondary write could permit a later dependent write to be recorded without the conditioning write (.g., a log entry indicating that a data base record has been updated when in reality the actual update write for the data base had failed violates the sequence integrity of the secondary DASD 416 copy).

A failed secondary 416 copy is unusable for application recovery until that failure to update has been recovered. The failed update could be corrected by having the SDM 414 request a current copy from the PDM 404. In the mean time the secondary data copy is inconsistent and hence unusable until the PDM 404 responds with the current update and all other previous updates are processed by the PDM 414. The time required to recover the failed update typically presents an unacceptably long window of non-recovery for adequate disaster recovery protection.

Effective secondary site 431 I/O optimization is realized by inspecting the data record sets to be written for a given consistency group and building chains based upon rules of the particular secondary DASD 416 architecture, for example, an ECKD architecture. The optimization technique disclosed herein simplifies recovery from I/O errors such that when applying a consistency group, if an I/O error occurs, the CCW chain can be re-executed, or in the event of a secondary initial program load (IPL) recovery, the entire consistency group can be re-applied without data loss.

FIG. 12 summarizes full consistency group recovery (FCGR) rules for building CCW chains for all WRITE I/O combinations for an ECKD architecture, wherein CCHHR record format is used (cylinder number, head number, record number). FIG. 12 is created by inspecting each possible combination of WRITE I/O operations to a DASD track within a consistency group's scope. The FCGR rules of FIG. 12, described in FIG.s 13A and 13B, are then followed to govern data placement (secondary DASD 416 I/O write CCW chains) for yielding full recovery for an error in applying a consistency group. The FCGR rules depicted in FIG. 12 would be extended appropriately as new WRITE I/O operations are added. These rules can exist in hardware or software at the secondary site 431. The FCGR rules advantageously reduces READ record set to a same DASD track analysis to an inspection of the primary DASD 406 WRITE I/O type, search argument, and count and key fields.

If a DASD track is written without inspecting the consistency group write operations as shown in FIG. 12, then previously written data records potentially cannot be re-written. For example, assume that a chain includes:

WRITE UPDATE to r cord five; and
FORMAT WRITE to record one,

wherein record one and record five occur on the same DASD track with record one preceding record five. R cord five is updated by an UPDATE WRITE CCW and a FORMAT WRITE I/O CCW updates record one erasing a remaind r of the track thus deleting record five. If this chain had to be re-executed, a LOCATE RECORD CCW that will position to the beginning of record five will no longer have a positioning point (record five no longer exists), and the chain is not fully recoverable from the beginning. Since the write operations have already been successful at the primary site 421, always being able to apply an entire consistency group on the secondary DASD 416 is required to maintain data consistency and integrity.

FIG. 14, steps 1410 through 1470, provides more detail as to the process represented by step 1160 of FIG. 11, while using the FCGR rules defined in FIG. 12. At step 1410 the SDM 414 divides the records of the current consistency group into two categories. A first category includes I/O orders directed to a same secondary DASD volume, and a second category includes I/O orders of those records in the first category that are directed to a same CCHH (i.e., records being updated to a same DASD track).

Having categorized the records of the current consistency group, step 1420 conforms application WRITE I/Os and SDM 414 WRITE I/Os to the architecture of the secondary DASDs 416, for example, to ECKD architecture FCGR rules (see FIG. 12) for identifying data placement on a track and track/record addressing. The SDM 414 groups secondary DASD WRITE I/O operations to the same volumes into single I/O CCW chains at step 1430. Step 1440 involves moving the head disk assembly (HDA) of each secondary DASD 416 according to search arguments and specific record data (CKD fields) for the actual secondary DASD 416 writes.

Step 1450 compares READ SET BUFFERS one and two for those records making up the second categories (there typically will be a plurality of second categories, one for each track receiving records), using the FCGR rules of FIG. 12 for determining whether a subsequent write operation invalidates a previous write operation or DASD search argument (positioning at a record that is now erased, etc.). The READ SET BUFFERS one and two contain adjacent read record sets. Following the FCGR rules ensures that the SDM 414 can re-write an entire consistency group, in the event of an error, without re-receiving record updates from the primary site 421. After the SDM 414 applies the current consistency group to the secondary DASD 416, step 1460 updates the state table (FIG. 7) and the master journal (FIG. 8).

The remote copy process continues in real time as step 1470 gets a next consistency group (which becomes the curr nt consistency group) and returns processing to st p 1410. The remote copy process will stop if the primary site 421 to secondary site 431 communication terminates. The communication may t rminate if volume pairs ar deleted from the proc ss by th PDM 404, th primary site is destroy d

(disaster ccurs), an orderly shutdown is performed, or a sp cific takeover action occurs at the secondary site 431. Consistency groups journal d on the secondary site 431 can be applied to th secondary DASD 416 during a takeover op ration. The only data lost is that data captured by the primary site 421 that has not been completely received by the SDM 414.

In summary, synchronous and asynchronous remote data duplexing systems have been described. The asynchronous remote data duplexing system provides storage based, real time data shadowing. A primary site runs applications generating record updates, and a secondary site, remote from the primary site, shadows the record updates and provides disaster recovery for the primary site. The asynchronous remote data duplexing system comprises a sysplex timer for synchronizing time dependent processes in the primary site, and a primary processor at the primary site for running the applications, the primary processor having a primary data mover therein. A plurality of primary storage controllers are coupled to the primary processor for issuing write I/O operations for each record update, each primary storage controller DASD write I/O operation being synchronized to the sysplex timer. A plurality of primary storage devices receive the write I/O operations and store the record updates therein accordingly. The primary data mover collects record set information from the plurality of primary storage controllers for each record update and appends a prefix header to a predetermined group of record set informations. The prefix header and predetermined group of record set informations form the self describing record sets. Each record set information includes a primary device address, a cylinder number and head number (CCHH), a record update sequence number, a write I/O type, a search argument, a sector number, and a record update time. The prefix header includes a total data length, an operational time stamp, a time interval group number, and a records read time. A secondary processor at the secondary site has a secondary data mover, the secondary data mover receiving the self describing record sets from the primary site. A plurality of secondary storage controllers are coupled to the secondary processor, and a plurality of secondary storage devices are coupled to the secondary storage controllers for storing the record updates copies. The secondary data mover determines whether the transmitted self describing record sets are complete and forms consistency groups from the self describing record sets and provides the record updates from each consistency group to the plurality of secondary storage controllers for writing to the plurality of secondary storage devices in an rder consistent with a sequence that the record updat s w r written to th plurality of primary storage devices.

Whil the invention has been particularly shown and describ d with referenc to preferr d embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the scope of the invention as defin d in the appended claims. For example, th consistency groups have been described as being formed by th secondary data mover based upon received self describing record sets, however, the consistency groups could be formed at the primary site based upon write record sets or elsewhere in the secondary site. The formats the storage devices at the primary and secondary sites need not be identical. For example, CKD records could be converted to fixed block architecture (FBA) type records, etc. Nor are the storage devices meant to be limited to DASD devices.

Claims

1. A method of providing asynchronous data duplexing, wherein data updates generated by one or more applications running in a primary processor are received by a primary storage subsystem, the primary storage subsystem causing I/O write operations to write each data update therein, each write I/O operation being time stamped, the time stamps synchronized by a common timer, and wherein a secondary system, whether local to or remote from the primary processor, shadows the data updates in sequence consistent order such that the secondary site is available for disaster recovery purposes, the method comprising the steps of:

   (a) time stamping each write I/O operation occurring in the primary storage subsystem;

   (b) capturing write I/O operation record set information from the primary storage subsystem for each data update;

   (c) generating self describing record sets from the data updates and respective record set informations, the self describing record sets containing sufficient control information to enable recreation of a sequence of the write I/O operations solely by the secondary system;

   (d) grouping the self describing record sets into interval groups, each interval group being measured from an operational time stamp start time and continuing for a predetermined interval threshold; and

   (e) selecting a current consistency group as that interval group of self describing record sets having an earliest operational time stamp, the individual data updates being ordered within the current consist ncy group based upon time sequences of the I/O write operations in the primary storage subsyst m.

2. The meth d as claimed in claim 1 wh rein the st p (b) further includes initiating sessions with th primary storage subsystem bas d upon the operati nal time stamps for identifying a starting time for each interval group, each interval group being bounded by consecutive operational time stamps.

3. The method as claimed in claim 1 or claim 2 wherein the step (d) includes adding a prefix header describing each interval group.

4. The method as claimed in any preceding claim further comprising a step (f) transmitting the interval groups of self describing record sets to the secondary site .

5. The method as claimed in claim 4 further comprising a step (g) determining at the secondary site whether each received self describing record set is complete.

6. The method as claimed in claim 5 wherein the step (g) further includes the secondary site requesting the primary site to re-transmit any missing data updates if the secondary site determined a self describing record set is incomplete.

7. The method as claimed in claim 6 further comprising a step (h) determining at the secondary site whether each time interval group is complete.

8. The method as claimed in claim 7 wherein the step (h) further includes the secondary site requesting the primary site to re-send a missing record set if the secondary site determined that an interval group was incomplete.

9. The method as claimed in claim 8 further comprising a step (i) writing the received data updates at the secondary site to the secondary storage subsystem according to the sequence of the corresponding write I/O operations at the primary site as ordered in the consistency groups.

10. A method for providing remote data shadowing for disaster recovery purposes in a data processing system including a primary site having a primary processor running a primary data mover and applications generating record updates, the primary processor coupled to a primary storage subsystem having st rage devices for storing th record updates according to write I/O op rations issu d by the primary processor to the primary storage subsyst m, th primary site further including a common system tim r for synchronizing tim dependent operations in the primary site, th system further including a secondary site having a secondary processor communicating with the primary processor, and a secondary storage subsystem for storing copies of the record updates in sequ nce consistent order, the method comprising the steps of:
(a) time stamping each write I/O operation in the primary storage subsystem;
(b) establishing a session with each storage device in the primary storage subsystem;
(c) capturing record set information from each storage device in the primary storage subsystem;
(d) reading record sets and respective record set information in the primary data mover;
(e) prefixing each record set with a header and creating self describing record sets therefrom;
(f) transmitting the self describing record sets to the secondary processor in time interval groups according to predetermined time intervals;
(g) forming consistency groups from the self describing record sets; and
(h) shadowing the record updates of each consistency group to the secondary storage subsystem in a sequence consistent order.

11. The method as claimed in claim 10 wherein the record sets are transmitted to the secondary processor asynchronously.

12. The method as claimed in claim 10 or claim 11 wherein the step (g) is performed at the secondary site.

13. The method as claimed in any of claims 10 to 12 wherein the step (f) further includes determining at the secondary site whether each received self describing record set is complete.

14. The method as claimed in claim 13 wherein the step (f) further includes requesting the primary site to re-transmit any missing record updates if the primary site determined a received self describing record set is incomplete.

15. The method as claimed in any of claims 10 to 14 further comprising a step (i) determining at the secondary site whether each time interval group is complete.

16. The method as claim d in claim 15 wherein the step (i) further includes requesting the primary site to re-send a missing record s t if th secondary sit d t rmin d that a interval group was incomplete.

17. The method as claimed in any of claims 10 to 16 wh r in the step (c) id ntifies, in the record set information, a physical l cation on the primary storage devices where ach record update is stored.

18. The method as claimed in claim 17 wherein the step (c) identifies, in the record set information, a sequence and time of update of each record update stored to the primary storage devices within the session.

19. The method as claimed in any of claims 10 to 18 wherein the step (e) identifies, in the prefix header, an interval group number for the session and sequence within group for each record update referred to therein.

20. A primary data processing system having a primary processor running one or more applications, the one or more applications generating record updates, the primary processor generating self describing record sets therefrom, the self describing record sets being sent to a secondary system, the secondary system shadowing the record updates in sequence consistent order based upon the self describing record sets for real time disaster recovery purposes, the primary processor being coupled to a primary storage subsystem wherein the primary storage subsystem receives the record updates and executes write I/O operations for storing each record update therein, the primary processor comprising:

a timer for providing a common time source to the applications and primary storage subsystem for synchronization purposes; and

primary data mover means prompting the primary storage subsystem for providing record set information to the primary data mover means for each record update, the primary data mover means grouping a plurality of record updates and each corresponding record set information into time interval groups, and inserting a prefix header thereto, each time interval group the self describing record sets. interval groups, and inserting a prefix header thereto, each time interval group the self describing record sets.

21. The primary system as claimed in claim 20 wherein the primary storage subsystem comprises:

a plurality of primary storage controllers, the plurality of primary storage controllers issuing the write I/O operations; and

a plurality of primary storage devices coupled to the plurality of primary storage controllers.

22. The primary system as claimed in claim 20 or claim 21 wherein the primary data mover means collects record set information for each write I/O operation for each primary storage controller of the plurality of primary storage controllers participating with each time interval group.

23. The primary system as claimed in any of claims 20 to 22 wherein each write I/O operation is time-stamped in the primary processor relative to the sysplex timer, each write I/O operation being issued to a primary storage controller of the plurality of primary storage controllers, each primary storage controller preserving the time-stamp and returning that time-stamp in the corresponding read record set to the primary data mover means.

24. The primary system as claimed in claim 23 wherein each record set information identifies a corresponding record update's physical location on a primary storage device of the plurality of primary storage devices.

25. The primary system as claimed in claim 23 or claim 24 wherein each record set information identifies a corresponding record update's primary subsystem identification, primary device address, cylinder number, and head number.

26. The primary system as claimed in claim 23 wherein the primary data mover means identifies a relative sequence of each write I/O update across all primary storage controllers participating in a time interval group.

27. The primary system as claimed in claim 26 wherein the primary data mover means creates a state table for journaling record updates and cross referencing a storage location of each record update on the primary system and the secondary system.

28. The primary system as claimed in claim 26 wherein the primary data mover means communicates the state table to the secondary system.

29. A remote data shadowing system including a primary site and a secondary site, the secondary site asynchronously shadowing record updates of the primary site in real time for disaster recovery purposes, the record updates generated by applications running at the primary site, the primary site comprising:

a sysplex timer;

a primary processor running the applications g nerating the record updates and issuing a corr sponding write I/O op ration for each record update, the primary processor having a pri-

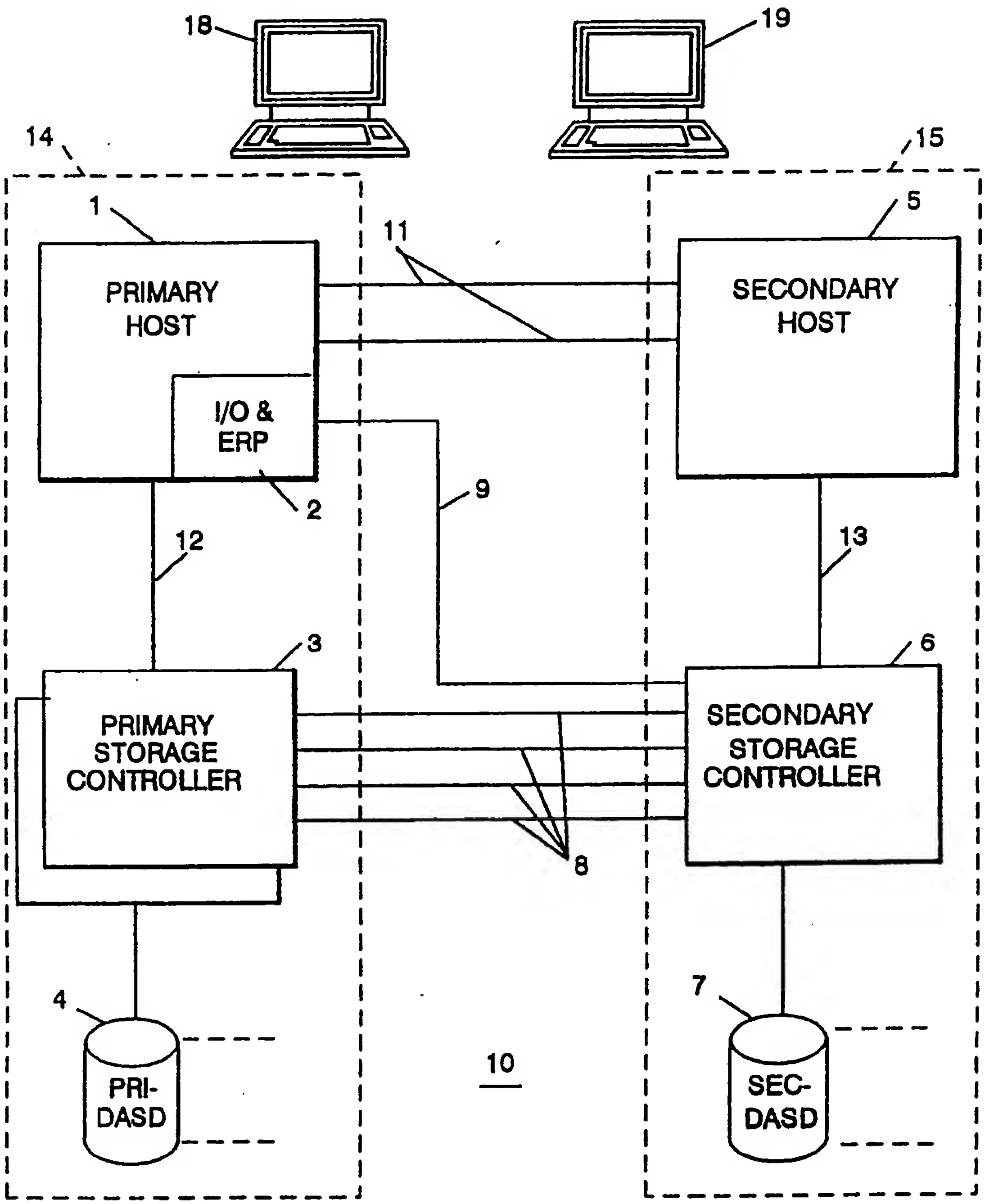
mary data mover therein;

a plurality of primary storage controllers direct d to store the record updates, th plurality of primary storage controllers executing the issued write I/O peration for each record update; and

a plurality of primary storage devices receiving and storing the record updates therein according to the corresponding write I/O operations,

wherein the primary processor and each write I/O are time-stamped by the primary processor, as synchronized by the sysplex timer, such that write I/O operations are accurately sequence ordered relative to each other, the primary data mover collecting sets of record updates and combining each record set information as provided by each one of the plurality of primary storage controllers with the corresponding record update, each record set information including a relative sequence and time of each corresponding write I/O operation, the primary data mover collecting record updates into time interval groups and inserting a prefix header to each time interval group, wherein the prefix header includes information identifying the record updates included in each time interval group, each record set information and prefix header combined for creating self describing record sets, the self describing record sets being transmitted to the secondary site, wherein the self describing record sets provide information adequate for the secondary site to shadow the record updates therein in sequence consistent order without further communications from the primary site.

FIG. 1


18
19
14
15
1
5
11
PRIMARY HOST
SECONDARY HOST
I/O & ERP
9
2
12
13
3
6
PRIMARY STORAGE CONTROLLER
SECONDARY STORAGE CONTROLLER
8
4
7
10
PRI-DASD
SEC-DASD

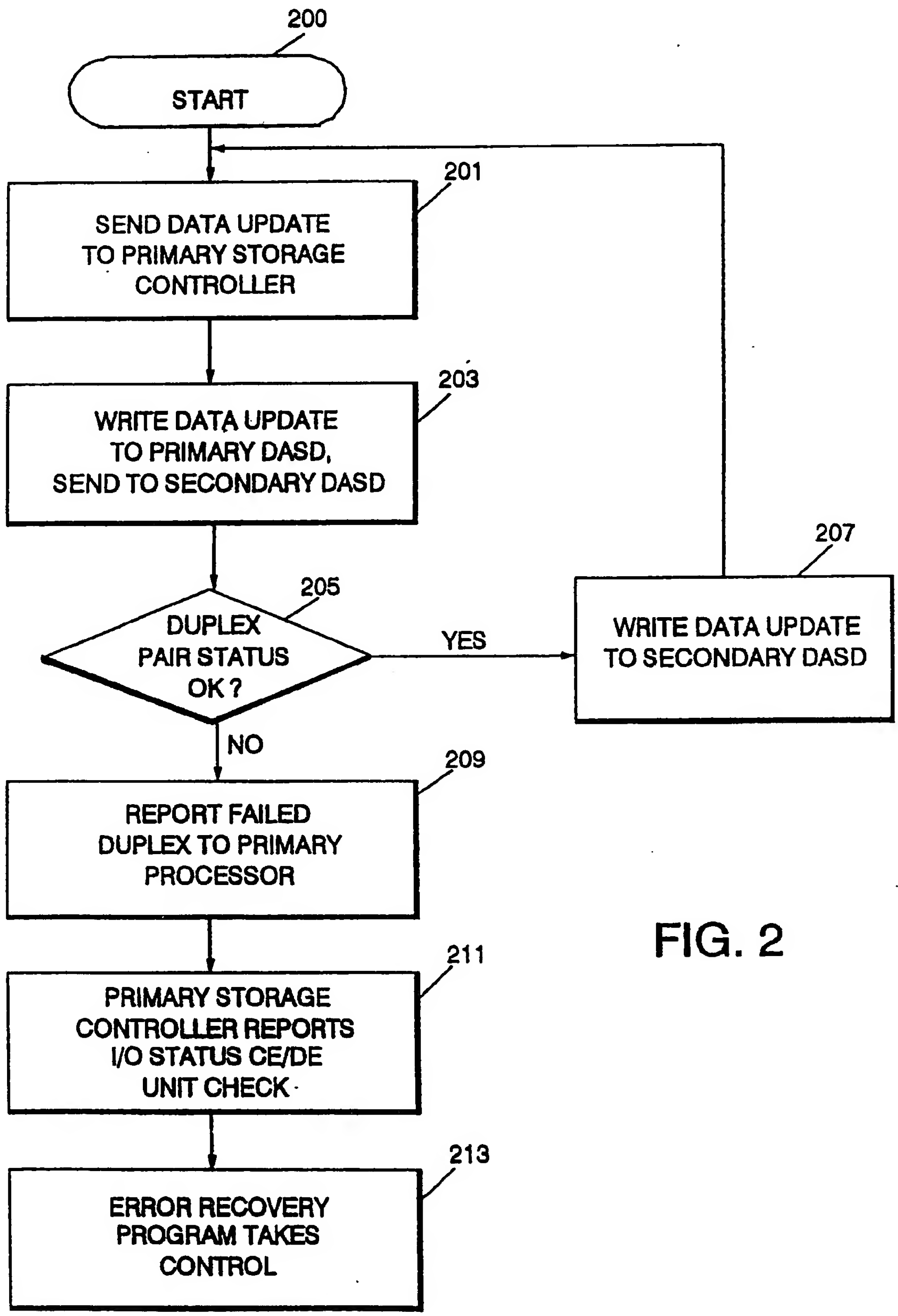

200
START
201
SEND DATA UPDATE TO PRIMARY STORAGE CONTROLLER
203
WRITE DATA UPDATE TO PRIMARY DASD, SEND TO SECONDARY DASD
205
DUPLEX PAIR STATUS OK ?
YES
207
WRITE DATA UPDATE TO SECONDARY DASD
NO
209
REPORT FAILED DUPLEX TO PRIMARY PROCESSOR
211
PRIMARY STORAGE CONTROLLER REPORTS I/O STATUS CE/DE UNIT CHECK
213
ERROR RECOVERY PROGRAM TAKES CONTROL

FIG. 2

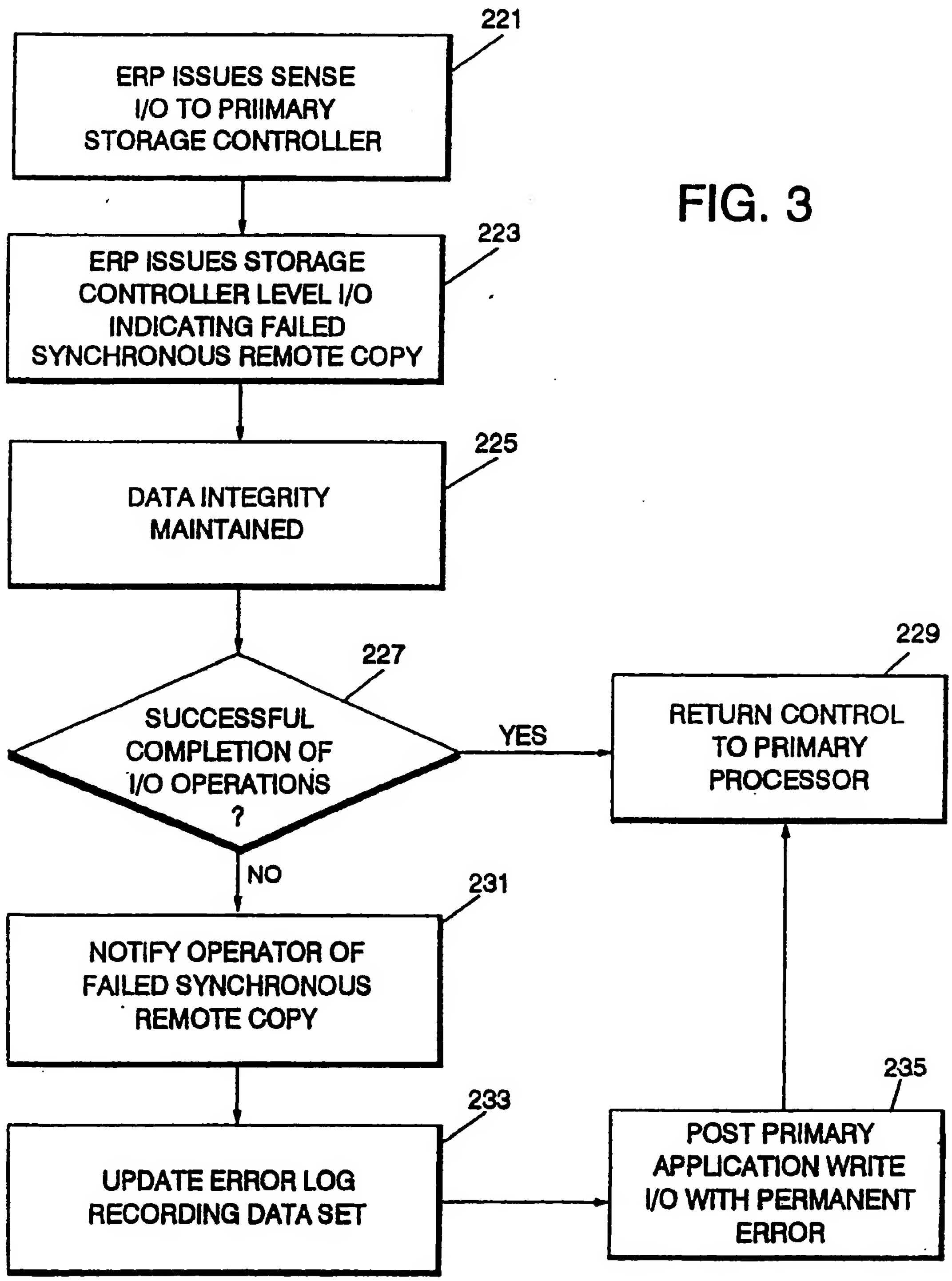

ERP ISSUES SENSE I/O TO PRIIMARY STORAGE CONTROLLER
221
ERP ISSUES STORAGE CONTROLLER LEVEL I/O INDICATING FAILED SYNCHRONOUS REMOTE COPY
223
DATA INTEGRITY MAINTAINED
225
SUCCESSFUL COMPLETION OF I/O OPERATIONS ?
227
YES
NO
RETURN CONTROL TO PRIMARY PROCESSOR
229
NOTIFY OPERATOR OF FAILED SYNCHRONOUS REMOTE COPY
231
UPDATE ERROR LOG RECORDING DATA SET
233
POST PRIMARY APPLICATION WRITE I/O WITH PERMANENT ERROR
235

FIG. 3

FIG. 4

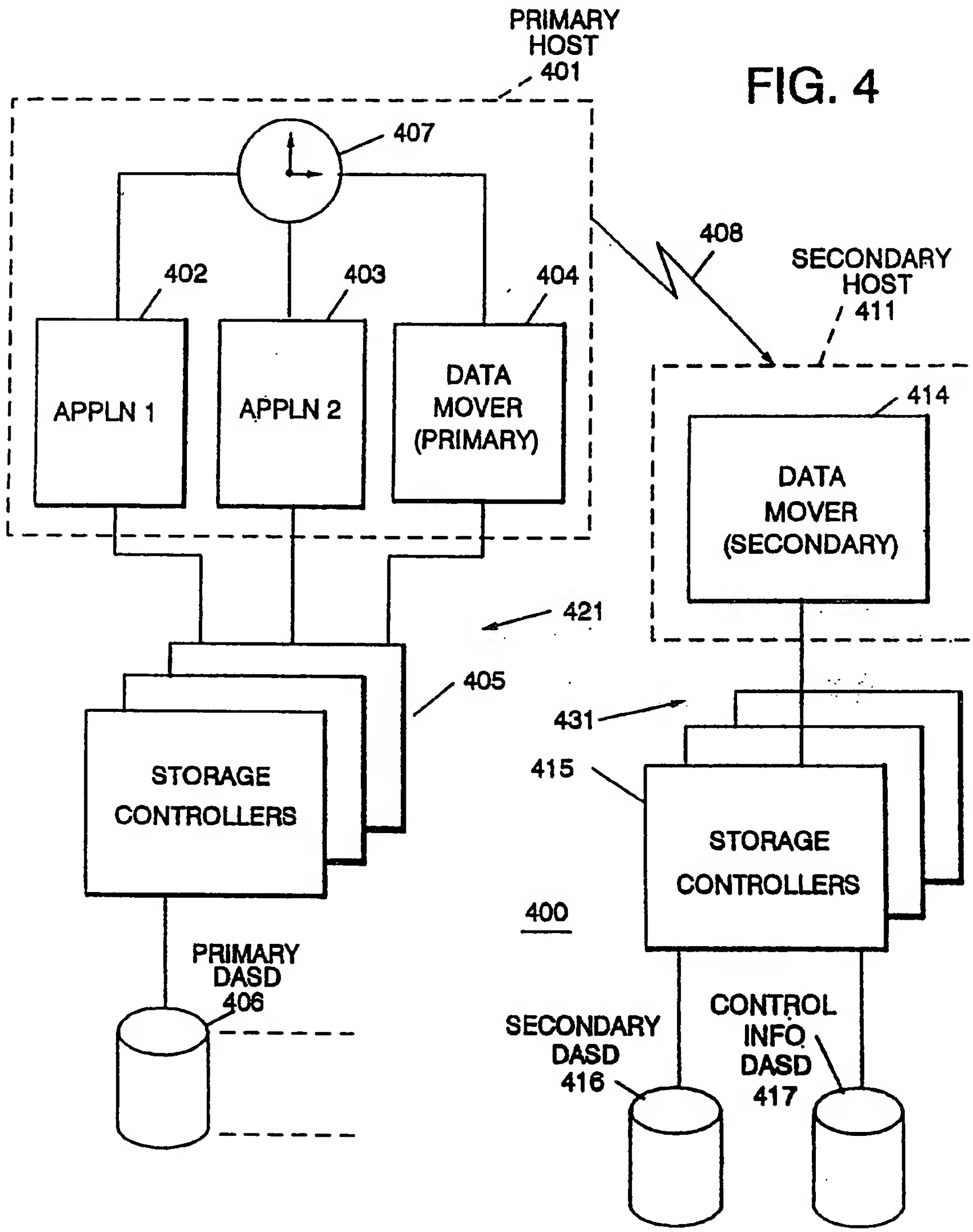
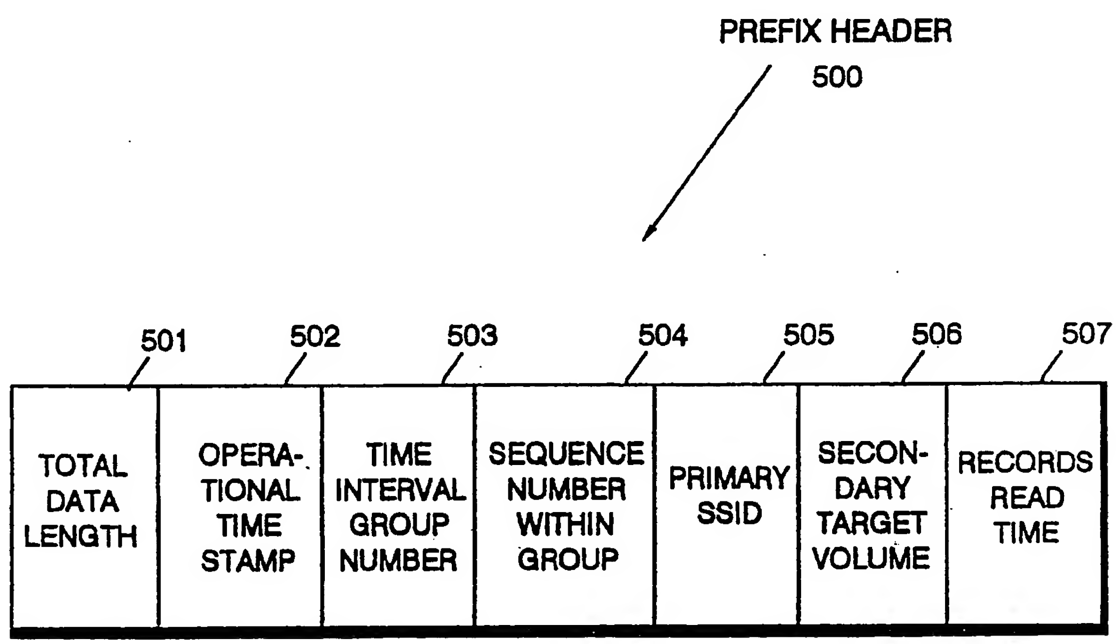

PRIMARY
HOST
401
407
408
SECONDARY
HOST
411
402
403
404
APPLN 1
APPLN 2
DATA
MOVER
(PRIMARY)
414
DATA
MOVER
(SECONDARY)
421
405
431
415
STORAGE
CONTROLLERS
STORAGE
CONTROLLERS
400
PRIMARY
DASD
406
SECONDARY
DASD
416
CONTROL
INFO
DASD
417

FIG. 5


PREFIX HEADER
500
501
502
503
504
505
506
507
TOTAL DATA LENGTH
OPERA-TIONAL TIME STAMP
TIME INTERVAL GROUP NUMBER
SEQUENCE NUMBER WITHIN GROUP
PRIMARY SSID
SECON-DARY TARGET VOLUME
RECORDS READ TIME

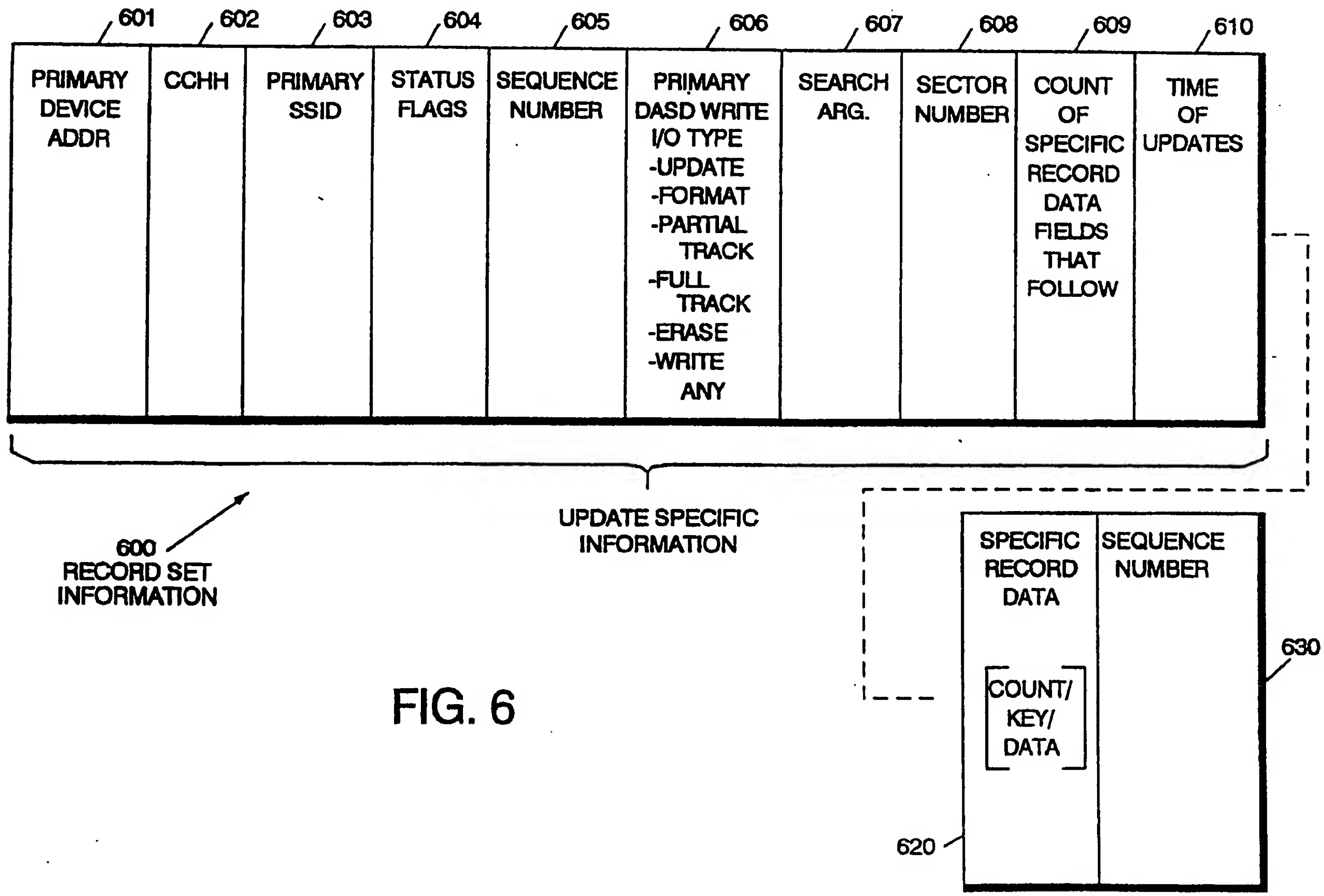
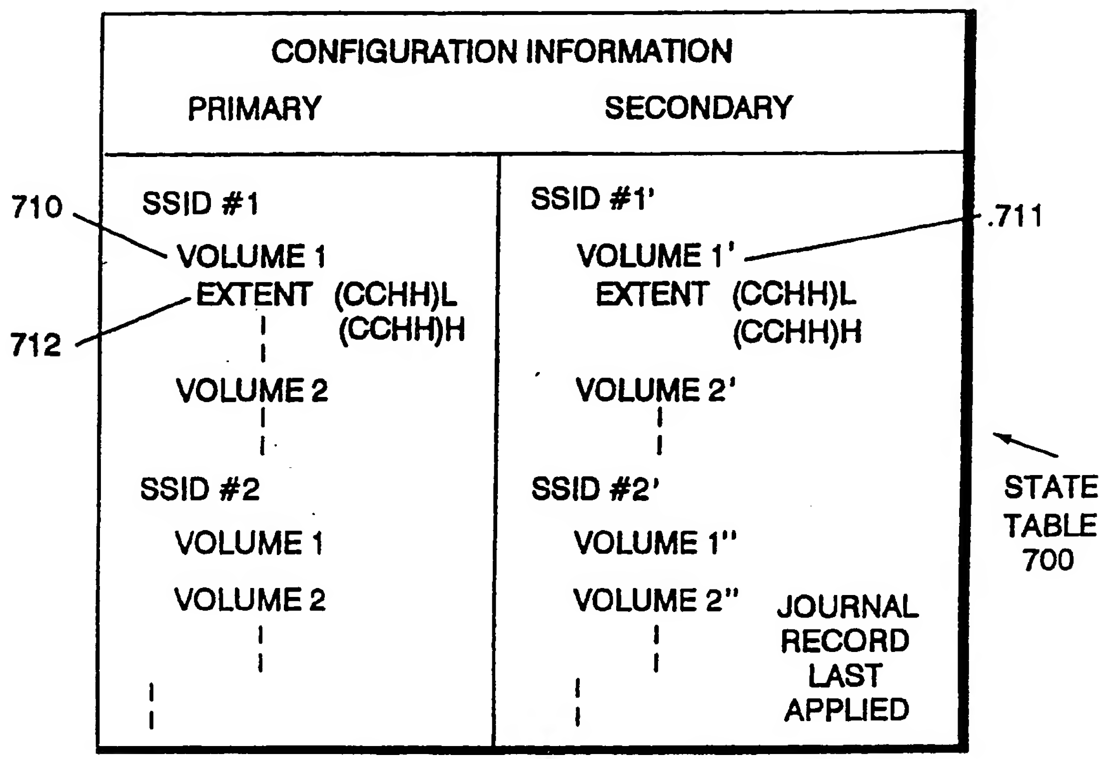

601
602
603
604
605
606
607
608
609
610
PRIMARY DEVICE ADDR
CCHH
PRIMARY SSID
STATUS FLAGS
SEQUENCE NUMBER
PRIMARY DASD WRITE I/O TYPE
-UPDATE
-FORMAT
-PARTIAL TRACK
-FULL TRACK
-ERASE
-WRITE ANY
SEARCH ARG.
SECTOR NUMBER
COUNT OF SPECIFIC RECORD DATA FIELDS THAT FOLLOW
TIME OF UPDATES
UPDATE SPECIFIC INFORMATION
600
RECORD SET INFORMATION
SPECIFIC RECORD DATA
COUNT/ KEY/ DATA
SEQUENCE NUMBER
620
630

FIG. 6

FIG. 7


CONFIGURATION INFORMATION
PRIMARY
SECONDARY
710
712
SSID #1
VOLUME 1
EXTENT (CCHH)L
(CCHH)H
VOLUME 2
SSID #2
VOLUME 1
VOLUME 2
SSID #1'
VOLUME 1'
EXTENT (CCHH)L
(CCHH)H
VOLUME 2'
SSID #2'
VOLUME 1"
VOLUME 2"
JOURNAL RECORD LAST APPLIED
.711
STATE TABLE 700

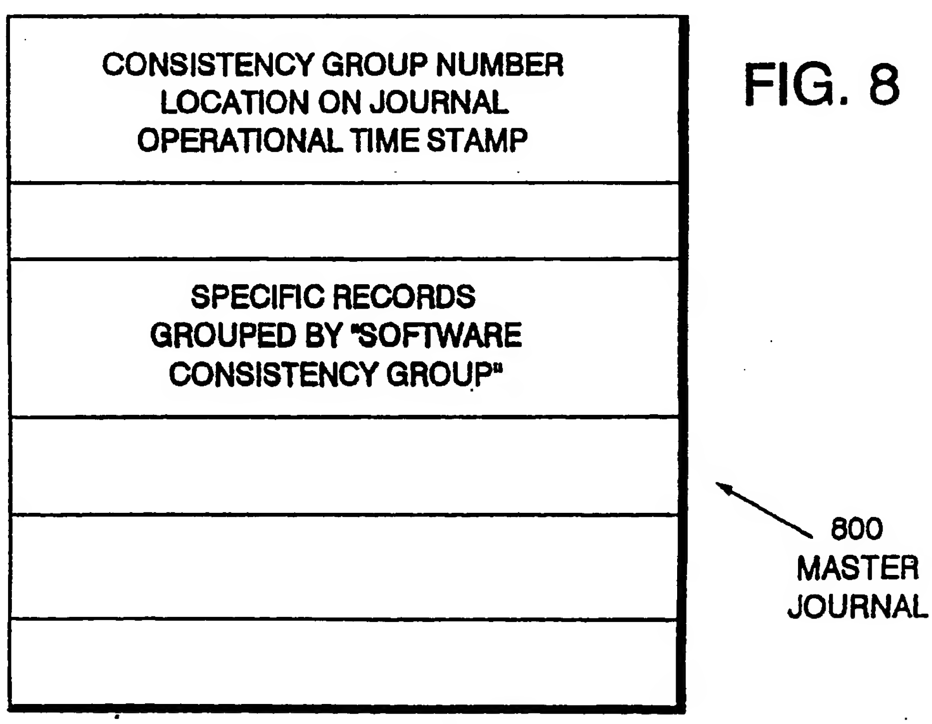

CONSISTENCY GROUP NUMBER
LOCATION ON JOURNAL
OPERATIONAL TIME STAMP
SPECIFIC RECORDS
GROUPED BY "SOFTWARE
CONSISTENCY GROUP"
800
MASTER JOURNAL

FIG. 8

FIG. 9

PHYSICAL CONTROLLER ID	OPERATIONAL TIME STAMP	TIME INT GROUP #	READ RECORD SET TIME OF UPDATE / CONTROLLER SEQ. 1 OF 3	SEQ. 2 OF 3	SEQ. 3 OF 3
SSID1	T_1	G_1	11:59 (2)	12:00 (5)	12:01 (6)
SSID2	T_1	G_1	12:00 (4)	* 12:02 (7)	———
SSID3	T_1	G_1	11:58 (1)	11:59 (3)	* 12:02 (8)
SSID1	T_2	G_2			
SSID2	T_2	G_2			
SSID3	T_2	G_2			
	T_3	G_3			

CONSISTENCY GROUP #1

(1) 11:58 — EARLIEST OPERATIONAL TIME T_1, EARLIEST TIME OF UPDATE ACROSS SSID, ORDERED IN READ SEQUENCE

(2) 11:59

(3) 11:59

(4) 12:00

(5) 12:00

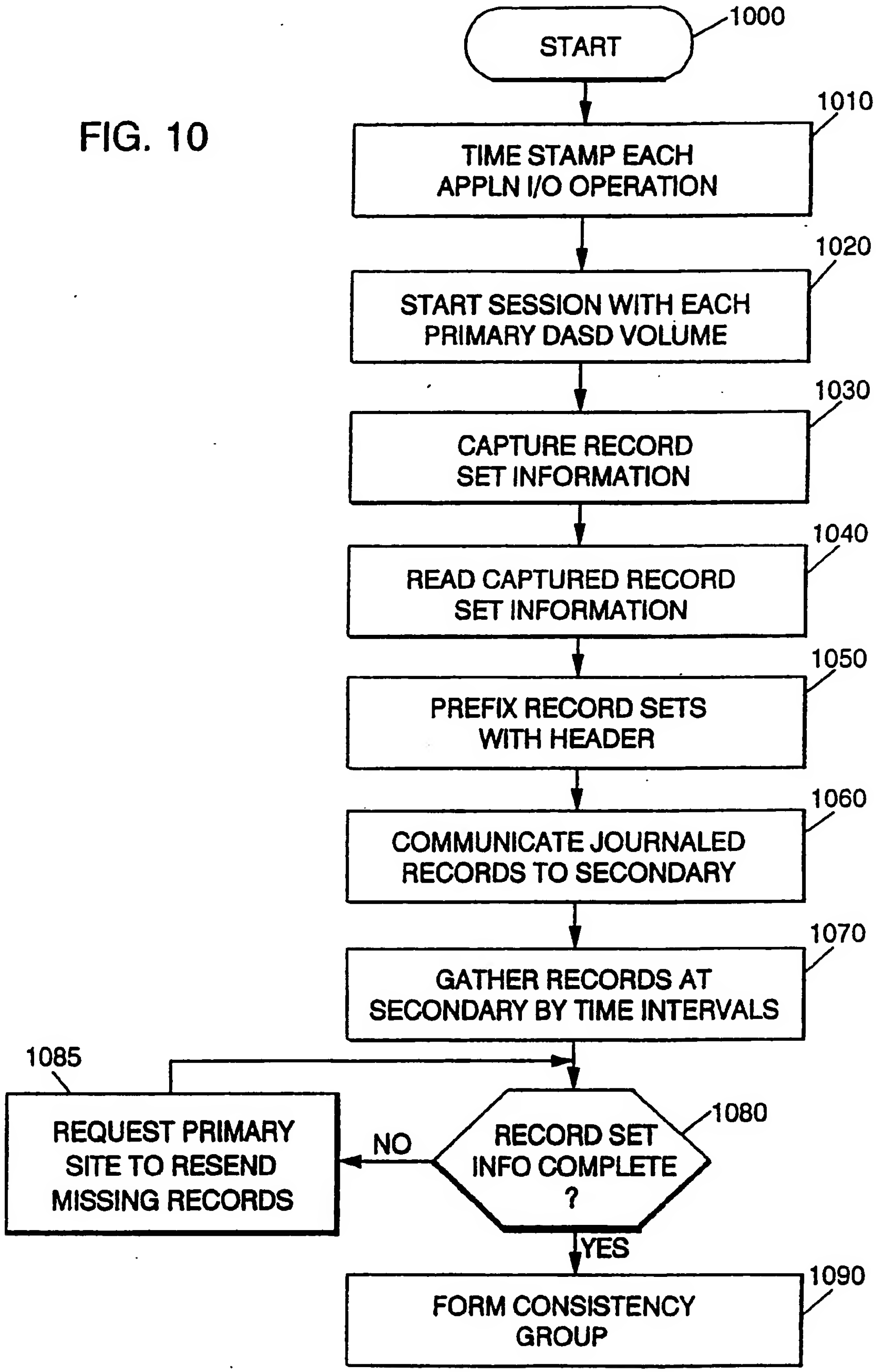
(6) 12:01 — MIN TIME OF THE MAX TIMES OF UPDATE ACROSS ALL SSIDS

CONSISTENCY GROUP #2

(7) - - - - -

(8) - - - - -

FIG. 10



START
1000
1010
TIME STAMP EACH APPLN I/O OPERATION
1020
START SESSION WITH EACH PRIMARY DASD VOLUME
1030
CAPTURE RECORD SET INFORMATION
1040
READ CAPTURED RECORD SET INFORMATION
1050
PREFIX RECORD SETS WITH HEADER
1060
COMMUNICATE JOURNALED RECORDS TO SECONDARY
1070
GATHER RECORDS AT SECONDARY BY TIME INTERVALS
1085
REQUEST PRIMARY SITE TO RESEND MISSING RECORDS
NO
1080
RECORD SET INFO COMPLETE ?
YES
1090
FORM CONSISTENCY GROUP

FIG. 11

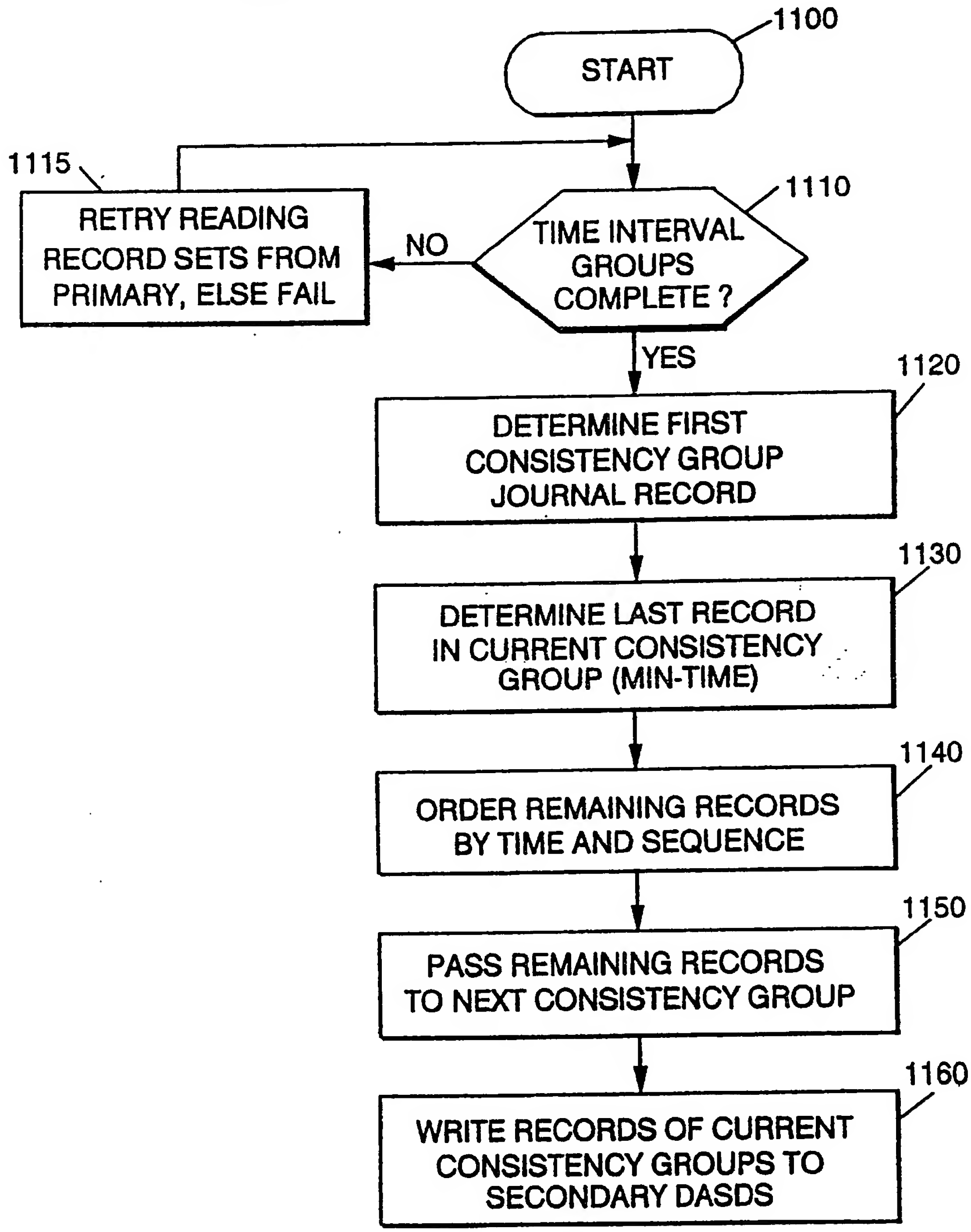

1100
START
1110
TIME INTERVAL GROUPS COMPLETE ?
NO
1115
RETRY READING RECORD SETS FROM PRIMARY, ELSE FAIL
YES
1120
DETERMINE FIRST CONSISTENCY GROUP JOURNAL RECORD
1130
DETERMINE LAST RECORD IN CURRENT CONSISTENCY GROUP (MIN-TIME)
1140
ORDER REMAINING RECORDS BY TIME AND SEQUENCE
1150
PASS REMAINING RECORDS TO NEXT CONSISTENCY GROUP
1160
WRITE RECORDS OF CURRENT CONSISTENCY GROUPS TO SECONDARY DASDS

FIG. 12

FULL CONSISTENCY GROUP RECOVERY RULES

READ RECORD SET BUFFER #2	READ RECORD SET BUFFER #1							
TYPE I/O WRITE OPERATION								
	UPDATE WRITE KL = 0	UPDATE WRITE KL ≠ 0	FORMAT WRITE FULL	FORMAT WRITE PARTIAL	ERASE FULL	ERASE PARTIAL	WRITE ANY KL = 0	WRITE ANY KL ≠ 0
UPDATE WRITE KL = 0	W*	E*	N	J	D	K	W	E*
UPDATE WRITE KL ≠ 0	E*	W*	N	J	D	K	E*	W
FORMAT WRITE FULL	T	T	R	T	R	T	R	R
FORMAT WRITE PARTIAL	C	C	N	H	F	L	W	W
ERASE FULL	T	T	R	R	R	T	T	T
ERASE PARTIAL	B	B	N	M	E	G	W	W
WRITE ANY KL = 0	W	E*	W	W	E	W	W	E*
WRITE ANY KL ≠ 0	E*	W	W	W	E	W	E*	W

FIG. 13

FIG. 13A

FIG. 13B

FIG. 13A

B - IF #1'S SEARCH ARG IS HIGHER THAN THE SEARCH ARG FOR #2, THEN THROW #1, ELSE DO BOTH.

C - IF #1'S RECORD IS EQUAL TO OR HIGHER THAN THE FIRST RECORD IN #2, THEN THROW #1, ELSE DO BOTH.

D - IF #2 IS UPDATING R0, THEN DO BOTH, ELSE ERROR.

E - ERROR (SHOULD NEVER HAPPEN).

E*- ERROR IF #1 AND #2 ARE THE SAME RECORD. (SHOULD NEVER HAPPEN WITHOUT A FORMAT WRITE IN BETWEEN).

F - IF FIRST RECORD IN #2 IS R1, THEN WRITE BOTH, ELSE ERROR.

G - IF #1'S SEARCH ARG IS EQUAL TO OR HIGHER THAN THE SEARCH ARG FOR #2, THEN THROW #1, ELSE ERROR.

H - IF #1'S SEARCH ARG IS HIGHER THAN THE LAST RECORD FOR #2. THEN THROW #1. ELSE IF #2'S SEARCH ARG IS HIGHER THAN THE LAST RECORD IN #1, THEN ERROR, ELSE WRITE BOTH.

TO OPTIMIZE FURTHER, CAN DO THE FOLLOWING. INSTEAD:

```
IF (1'S SEARCH IS EQUAL TO OR HIGHER THAN THE LAST RECORD
      IN #2) OR (THE LAST RECORD IN #1 IS EQUAL TO OR
      HIGHER THAN THE LAST RECORD IN #2) AND (2'S SEARCH
      IS LESS THAN OR EQUAL TO THE LAST RECORD IN #1)
  THEN THROW 1
  ELSE IF (#2'S SEARCH ARG IS HIGHER THAN THE LAST RECORD
            IN #1)
            THEN ERROR
            ELSE WRITE BOTH
```

J - IF #2'S RECORD (OR SEARCH) IS HIGHER THAN THE LAST RECORD IN #1, THEN ERROR, ELSE WRITE BOTH.

K -IF #2'S RECORD (OR SEARCH) IS HIGHER THAN #1'S SEARCH, THEN ERROR, ELSE WRITE BOTH.

L -IF #1'S SEARCH ARG IS EQUAL TO OR HIGHER THAN #2'S SEARCH ARG THEN EITHER WRITE BOTH OR OK TO THROW #1, ELSE ERROR.

M -IF (#1'S SEARCH ARG IS EQUAL TO OR HIGHER THAN #2'S SEARCH ARG) THEN THROW 1
ELSE IF (#2'S SEARCH ARG IS HIGHER THAN THE LAST RECORD IN #1)
THEN ERROR
ELSE WRITE BOTH.

N -IF #2'S SEARCH ARG IS HIGHER THAN THE LAST RECORD IN #1, THEN ERROR, ELSE WRITE BOTH.

R -OK TO THROW #1.

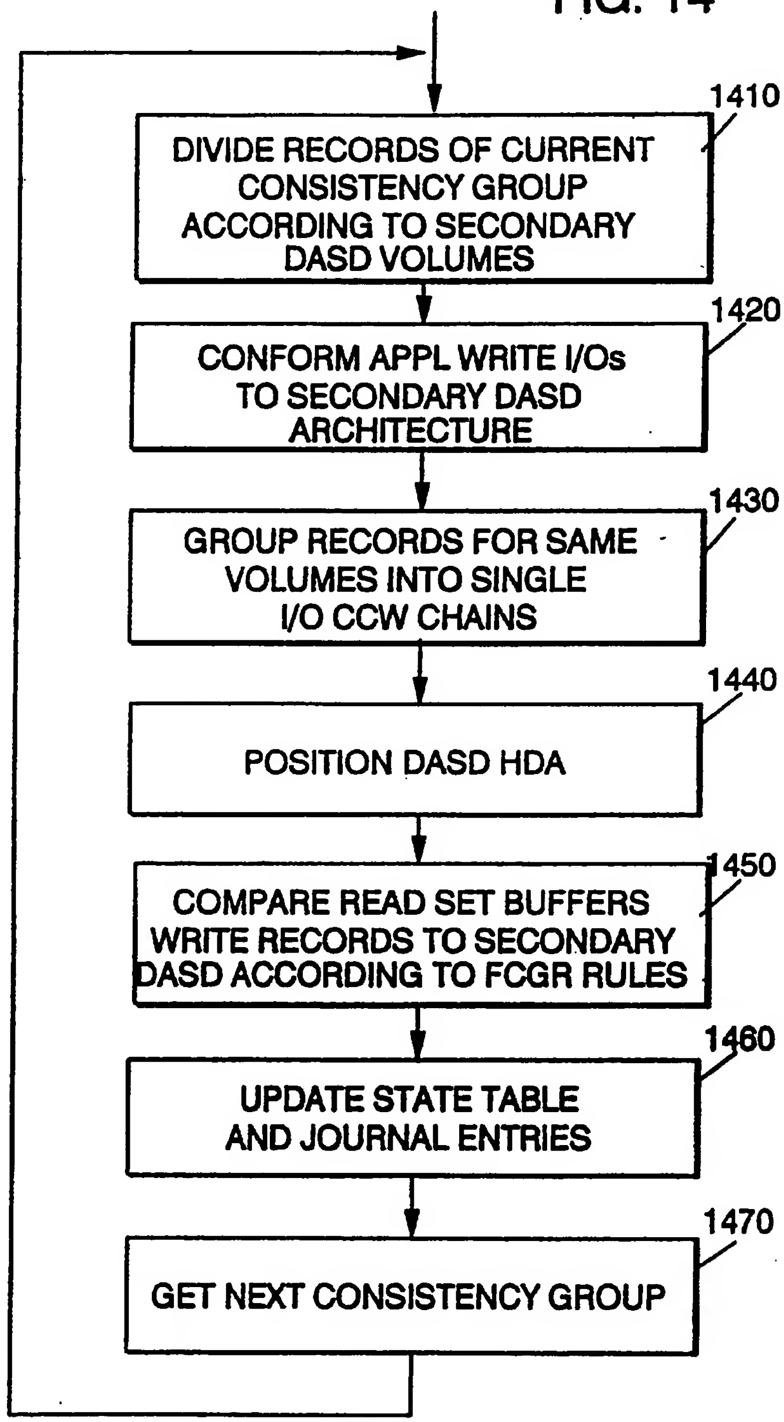
T -MUST THROW 1.

W -WRITE BOTH.

W*-IF #1 AND #2 HAVE THE SAME RECORDS, THEN THROW #1, ELSE DO BOTH OR MERGE RECORDS AND DO ONE WRITE.

FIG. 13B

FIG. 14


1410
DIVIDE RECORDS OF CURRENT CONSISTENCY GROUP ACCORDING TO SECONDARY DASD VOLUMES
1420
CONFORM APPL WRITE I/Os TO SECONDARY DASD ARCHITECTURE
1430
GROUP RECORDS FOR SAME VOLUMES INTO SINGLE I/O CCW CHAINS
1440
POSITION DASD HDA
1450
COMPARE READ SET BUFFERS WRITE RECORDS TO SECONDARY DASD ACCORDING TO FCGR RULES
1460
UPDATE STATE TABLE AND JOURNAL ENTRIES
1470
GET NEXT CONSISTENCY GROUP

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 95 30 0753

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	WO-A-91 20034 (STORAGE TECHNOLOGY CORP) 26 December 1991 * abstract * * page 13, line 6 - page 14, line 20 * * page 18, line 34 - page 19, line 6 * * page 20, line 1 - line 35 * * figure 3 *	1,10,20, 21,29	G06F11/14 G06F11/20
A	PROCEEDINGS OF THE ACM SIGMOD INTERNATIONAL CONFERENCE ON MANAGEMEN OF DATA, SAN DIEGO, JUNE 2 - 5, 1992, vol. 21, STONEBRAKER M, pages 236-245, XP 000393592 ANUPAM BHIDE ET AL 'AN EFFICIENT SCHEME FOR PROVIDING HIGH AVAILABILITY' * abstract * * page 237, left column, line 36 - right column, line 52 *	1,11,20, 29	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)
G06F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
BERLIN	27 June 1995	Masche, C

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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